

Effective Coordination of Technical and Social Components During the Design and Launch of a New Lean Manufacturing Work System

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Abstract

This research tests the hypothesis that when implementing lean manufacturing, explicit considerations must be made concerning the interrelationships of technical and social aspects work design. By definition, lean manufacturing systems blend humans and machines in the most profitable combination. This careful blend does not just happen. It must be planned and executed, and this has proven to be very difficult for most brownfield manufacturing sites that have a deep rooted mass production culture. The marriage of human and machine begins with the assumption that production workers are important contributors to the goals of the enterprise, and it continues on with manufacturing system and organizational designs that reflect that belief. Companies that have developed competencies in designing systems that remove as much human interaction in the manufacturing process as possible are now asked to throw away their collective mental models concerning mass production and embrace a new philosophy. The notion addressed in this thesis is that if the launch of a new lean manufacturing system in an existing facility is managed skillfully, with proper attention given to both the technical and social aspects of the initiative, that implementation will be successful. Just as with the operation of a lean manufacturing system, the design and launch processes must also be a harmonic blend of people and technology.

A research program centering around the design and implementation of a production system was used to test this hypothesis. Two parts of the launch were conducted in a decidedly different fashion than in previous launches at this site: the use of a cross functional team in implementation, and the introduction of a planning tool that explicitly coupled both social and technical tasks into the same framework. Preliminary results show these methods to benefit the overall launch process.

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1. Introduction

1.1 Background

By definition, lean manufacturing systems attempt to blend humans and machines in the most beneficial combination. Properly executed, this optimal mix of human and physical capital will create a system that produces what the customer wants, when they want it, with low cost and high quality. Autonomation¹, a word coined to describe this blend of human intuition and physical finesse with technology, is defined as the marriage of human and machine to achieve the proper balance between flexibility, speed, and cost. This careful blend does not just happen. It must be planned and executed, and this has proven to be very difficult for most brownfield manufacturing sites that have deep rooted culture surrounding traditional mass production systems.

Under old mass production beliefs, management's assumption was that employees are irresponsible and recalcitrant. As a result, both manufacturing technology and organizational structures were designed to ensure compliance, minimize employee's scope of discretion, and reduce reliance on employees for the quality and cost of the end product. Employees often responded to these systems with antagonism, thus reinforcing management's initial assumptions.

The move toward lean requires that this cycle be broken. The marriage of human and machine begins with the assumption that production workers are important contributors to the goals of the enterprise, and it continues on with manufacturing system and organizational designs that reflect that belief. Companies that embrace this belief and successfully implement lean systems have proven to be formidable competitors in the marketplace, but making the transition from mass production to lean manufacturing is not easy.

¹ Appendix 1 contains a full list of definitions surrounding the topics covered in this thesis.

Companies that have developed competencies in designing systems that remove as much human interaction in the manufacturing process as possible are now asked to throw away their collective mental models concerning mass production and embrace a new philosophy. It is logical then, that a combination of suspicion and lack of knowledge create barriers against the transformation to lean. These barriers are often reinforced when, at plants attempting the transformation in the midst of meeting current customer demands, the new systems fail to produce immediate results. Thus, it is no surprise that history shows very clearly that new plants that undergo a complete shut down during the transformation process are much more successful in embracing lean practices than those that attempt the transformation while still in operation.

This thesis addresses that issue. The hypothesis generated at the beginning of the research was that if the launch of a new lean manufacturing system in an existing facility was managed skillfully, with proper attention given to both the technical and social aspects of the initiative, that implementation would be successful. Just as with the operation of the manufacturing system, the design and launch processes must also be a harmonic blend of humans and technology.

1.2 Objectives

The goal of this thesis is to create a heightened awareness of the linkage between the technical and social sides of a manufacturing system launch, and to have readers use this awareness in designing and launching successful lean systems. Other goals of this thesis are as follows:

- To provide a planning and control framework for the launch of a manufacturing system.
- To show that the linkages between the social and technical sides of a lean launch can be leveraged to the benefit of the overall system.
- To introduce a change model that is tailored to the mass-to-lean transformation process.

1.3 Overview

This thesis is divided into three subsections that fit together but are meant also to be standalone resources for manufacturing facilities embarking on a lean transition. The second chapter is meant to provide background information, and to be a statement of the problem. Its target audience is anyone who wishes to learn more about lean manufacturing and the challenges involved with making a transformation to it from mass production. The third and fourth chapters are part of a case study at the research site. Chapter four was separated from the bulk of the case study because it specifically addresses a new technique for planning and managing a lean transformation. Finally, Chapter five presents a change model for moving from mass to lean based on the experiences of Chapters three and four.

Chapter 2: “The Challenge of Designing and Launching A Lean Manufacturing System”

Presents the problem of how to effectively address the launch of a manufacturing system from both the technical and social perspectives. It also provides an overview of lean manufacturing principles and some of the challenges associated with implementation at brownfield locations. This section uses specific examples to show what happens when the social and technical objectives are out of balance.

Chapter 3: “A Case Study in the Design and Implementation of a Lean Manufacturing System”

This section documents the design and launch of a manufacturing system through the experience of the author who was intimately involved in the launch team. The chapter starts with a history of the plant and specific business unit, and then the physical design of the system is discussed along with some reflection on the launch process. Data presented includes engineering and financial results from the design of the work system and interview data from several members of the launch team. Tying the data together will be a set of “lessons learned” from the experience.

Chapter 4: “Project Management using the Enhanced Critical Path Method”

At the beginning of the project, both social and technical tasks were drawn up, and a critical path chart was developed to control and monitor the project. The chart was organized such that social, technical, and social-technical milestones were documented in the same space. This allowed the launch team to be cognizant of social and technical events simultaneously.

This chapter is a discussion of the use of the Enhanced Critical Path, and it also addresses successes and failures of the project based on task completion data extracted from the critical path chart.

Chapter 5: “A Guide for Planning and Executing a Successful Manufacturing System Launch”

Provides a change model for launch teams embarking on the design and implementation of a new lean work system. This model represents learnings from the case presented in Chapters three and four as well as the over 150 years of combined experience (including dozens of product launches) of the launch team members.

1.4 Research Note

The author completed all of this research under the auspices of an Action Researcher. Action research places the researcher as an integral part of the work being performed. All of my counterparts were aware of my agenda. Sometimes I would wear my Company hat; sometimes I would wear my researcher hat, but most of the time I would balance the two roles. It was often difficult for the team of people whom I was working with (and me) to know ‘what hat’ I was wearing at any given time. This is important because, just as the Heisenberg Principle illustrates when studying physics, measurements will always be affected by the tool used to take them. In this case, my involvement in the project was large. My responsibilities included helping the launch team with project planning, assisting with engineering, and aiding with workgroup coordination. On one hand, my involvement may have added or detracted from the overall success of the project, and that

will have a large affect on the data presented here. On the other hand, because of my intimate knowledge of the process, the following insights will be richer than they would have been if they were written from a hands-off perspective. It is up to the reader to interpret the data accordingly.

2. The Challenge of Designing and Launching A Lean Manufacturing System

2.1 Introduction

“The hard stuff is easy. The soft stuff is hard. And the soft stuff is more important than the hard stuff.” – Steven Wheelwright

Wheelwright is correct on each account except for the first one – especially when the “hard stuff” is associated with the transformation of a brownfield site. Old sites are often a quagmire of old and new processes, complicated material handling, and a plant layout that was conceived through the “put it where there is room” method of space allocation. On top of this, any logistics that guide the installation of new manufacturing systems must deal with the ongoing task of meeting current customer demands. Wheelwright’s point, especially when aimed at existing plants with deeply rooted culture, is more representative if one considers that “soft” stuff often gets lost in the fray of new manufacturing system designs and the latest flavor-of-the-month management technique. Simply put, the “hard” stuff is more sexy and often holds the promise of quick and relatively painless results.

In the past two decades the principles of lean manufacturing have transcended from just another new management fad to a proven method of reducing cost, increasing customer service and quality, and improving job satisfaction of management and workforce alike. This transformation has happened as manufacturing organizations realized that bits and pieces of the system (JIT, workgroups, cellular manufacturing) were ineffective when implemented on their own but powerful when utilized in harmony with each other. Evidence abounded at plants like Toyota Georgetown and the GM/Toyota NUMMI joint venture that mass production was indeed a passé way of doing business. Plants throughout the world (including in Japan) are now on the road to transforming their current mass production systems to leaner systems.

When a company decides to improve its manufacturing processes by becoming lean, it is making two commitments – one to change the technical systems by which it manufactures goods, and another to change the social systems that support manufacturing processes. Many companies have been through periods of tension and uncertainty when new technology comes to the manufacturing floor. If new equipment contains significant technology – such as replacing a manual assembly process with an automated one – companies are normally forced into replacing their “low tech” workers with “high tech” engineers and technicians. This replacement of direct labor with indirect labor is never accepted readily by the existing workforce (and certainly not by labor unions), and very often, total production costs actually rise because automated systems are inflexible and expensive to maintain.

Moving from traditional manufacturing practices to lean manufacturing practices at a brownfield site, however, is more complex socially than putting in place automated systems. Lean systems don’t necessarily contain high levels of automation. They are often less automated than the systems that they replace. More importantly, lean systems require that the workforce be multi-skilled, highly motivated, and proactive in continually improving their work system. The physical systems that lean manufacturing is based on, therefore, require different skills to operate than many current workforces exhibit. The challenge then, when launching a new lean manufacturing system, is to coordinate the technical tasks of designing and installing equipment with the social tasks of choosing and creating highly effective workgroups from the existing labor pool.

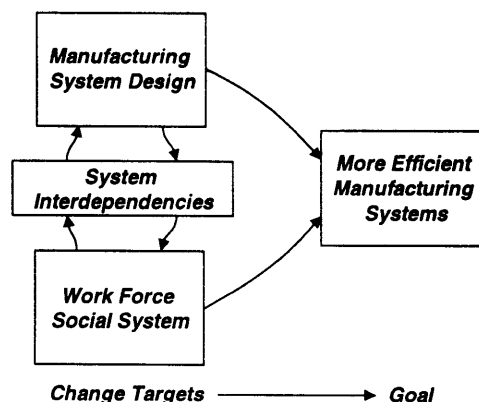


Figure 2.1. The technical and social interdependencies of a new manufacturing

Figure 2.1 shows the relationship between social and technical tasks. Within this relationship there is an opportunity to leverage social and technical interdependencies to create a high performance manufacturing system. As the arrows in the figure indicate, communication between the technical side (manufacturing engineering and machine suppliers) and the social side (production workers, management, Human Resources, union committee members) is important in the creation of such a system. Planning the form, timing, and content of these communications is a critical element in launch success.

There are several reasons why the formulation and follow through of a comprehensive plan that takes into account both social and technical factors is important:

- Speed is of great importance in today's fast paced economy, and that requires that manufacturing systems be up and running in short order at predictable volume and quality levels. Therefore, the entire work system (people and machines) must be working in harmony soon after launch. The only way to insure that happens is to simultaneously concentrate on technical and social issues.
- Resistance to change is always present. By concentrating simultaneously on social and technical issues the launch team is creating a shared vision of the future. This buy-in has cascading effects for each following lean system that is launched.
- Work system design will improve. By having the work team involved in the launch process, there exists an opportunity to leverage their tacit working knowledge of the job. These ideas can benefit ergonomics, efficiency and safety.
- Up front, early workgroup training will allow the team's capabilities to grow before launch. Taking the opportunity to improve technical and communication skills earlier rather than later has many ripple effects throughout the work system – before and after launch.

- The development of strong, two-way communication channels between the workforce and management creates feedback mechanisms important for future continuous improvement efforts.

Thus, the implicit point is that when making a transition from mass production to lean manufacturing there are difficult social and technical hurdles to overcome. A good basis for understanding the magnitude of this transition is a brief overview of lean manufacturing from three different perspectives: Historical, Technical and Social.

2.2 A Short History of Lean Manufacturing

All pundits of lean manufacturing agree that it was Toyota's Taiichi Ohno along with Shigeo Shingo and Kiichiro Toyoda that pioneered the lean model in the years just following World War II. They first started experimenting with ways of arranging machinery that would reduce the capital required to keep an automotive plant running. At the time, Toyota was trying to re-enter the automobile business, and their bankers would only finance production of automobiles for orders already placed at dealers. This forced Ohno to operate in small run sizes. Workers were responsible for adding direct labor when an order needed to be filled, and when the line was down they did maintenance and housekeeping. Capital intensive equipment like large machine tools and stamping presses were equipped with systems for rapid changeover between models to maximize uptime when running small batches, and Just-in-Time (JIT) delivery of parts minimized inventory costs. This "lean" method (a term coined in the book *The Machine that Changed the World*[1]) contrasted greatly with how most components were built in the US. In the United States mass production techniques centered around machine efficiency, and machines were most efficient if they were concentrated in one area, were run by a group of people that were experts in that equipment, and ran long runs of a single part. What resulted was a system that had a batch of parts being operated on by one group of similar machines, and then waiting to be operated on by another group of machines and so on until the batch of parts was complete. This mass production operation required

large investments in in-process inventory, and was too expensive for Toyota in the post-war years.

Toyota discovered that this new production experiment not only reduced the capital costs of making a product, but it also led to higher quality, shorter throughput time, reduced floor space, and an overall reduction in production machinery investment. A major requirement of being able to run this way was that factory floor workers' roles would be much different. Rather than staying in one place on a machining or assembly line and doing the same repetitive job over and over, the worker was now responsible for completing many tasks throughout the production process. This was commonly done in an atmosphere of teamwork because with very little inventory to buffer one operation from the next, a problem would halt production until the team came up with a solution. This work system design enabled workers to have a much bigger say in running day-to-day operations, and in improving the production system over time.

So, what are the principles behind this type of work system design? What are the guidelines that should be followed to ensure that the system is lean? The answer to those questions can be found in the system design and process principles that are necessary for lean manufacturing.

2.3 Lean Manufacturing System Technical Framework - Machines and Processes

Lean manufacturing has four basic goals: perfect quality, responsiveness, flexibility, and low cost. These are not stand alone concepts; they are interwoven in a complex web, and implementing only part of the process can actually lead to decreased performance. For example, many companies jumped on the JIT bandwagon, only to realize after considerable cost and frustration, that neither their manufacturing system, nor their business practices were supportive of operating in that manner. In order to show how system design is impacted by the basic principles of lean, it is important to understand the basic technical framework of lean manufacturing. For a more complete discourse on how

to design a complete lean manufacturing systems, there exist several references that supply that type of detailed information [2,3].

2.3.1 Lean Manufacturing Principles and Practices

There are certain physical artifacts and operating principles of lean manufacturing systems that characterize them from mass production systems. Traditionally, mass production systems were designed around the goals of reducing direct labor and increasing machine utilization. These two goals go hand-in-hand because eliminating labor usually requires expensive, complex machines, and in order to justify their high cost, they must be utilized to the fullest extent possible. Also implicit in these goals are the underlying assumptions that the manufacturing technology should ensure compliance, minimize the workers' scope of discretion, and reduce any reliance on worker skills. Conversely, lean systems, as modeled after the Toyota approach, have several key elements that are much different than mass production systems. These elements are the following:

Single Piece Flow

Single piece flow refers to parts being scheduled to run through a manufacturing system in a batch size of one. Unlike a more traditional system, which may have many hundreds of parts being operated on in a batch before being advanced to the next machine, single piece flow systems move parts individually between machines. This strategy has many advantages including reduced inventory, quicker changeovers, reduced throughput time, and increased quality.

A good way to illustrate some of these benefits is through an example. Figure 2.2 shows two manufacturing systems. One operates in a traditional batch and queue method, and one is operates using single piece flow. Immediately noticeable in the figure is that there is a lot of extra inventory space required to operate with batches. This inventory is expensive in many ways: it carries a high capital cost because it is tying up cash that could be put to better use, it is prone to damage, it could become obsolete, it takes up

floor valuable floor space, and transportation costs for batches are often high. Equally menacing is the possibility that a quality problem could be lurking in a batch somewhere that wasn't caught until the next operation. A problem like this could mean completely reworking or scrapping the entire batch.

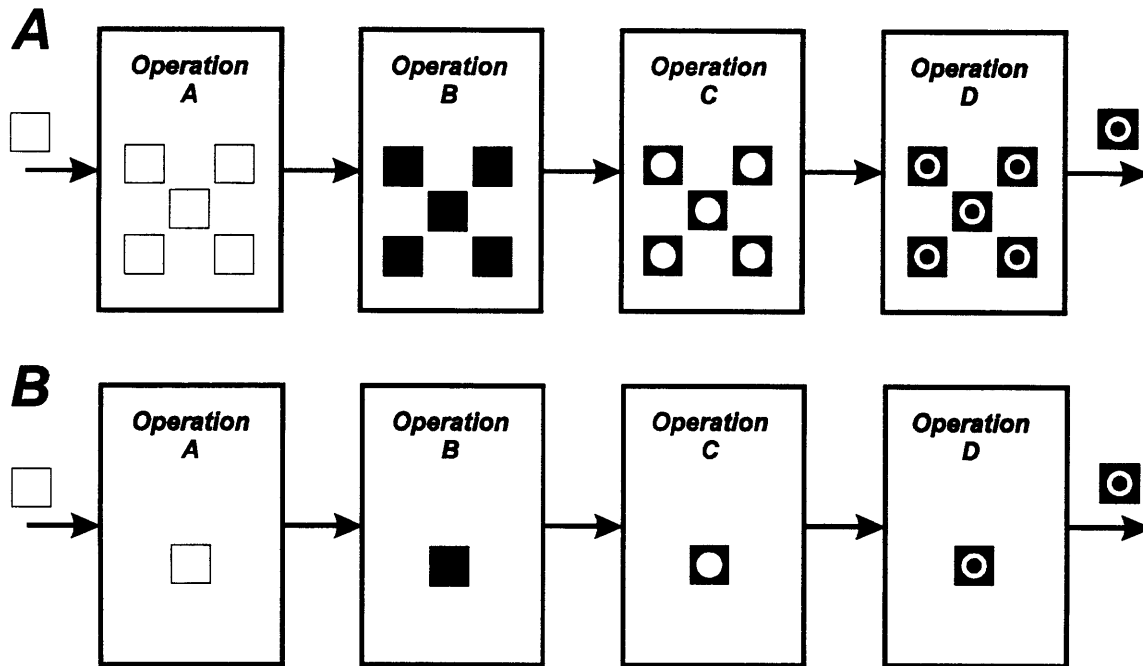


Figure 2.2. System A – Batch and queue. System B – single piece flow. Work in Process is shown as square “parts”.

Manufacturing system responsiveness is also sacrificed when operating with large run sizes. Consider the following example: If a single part were to be followed through each system, and each machine had a cycle time of one minute, System B would have a throughput time of only four minutes (one minute at each machine). On the other hand, the part in System A would take 20 minutes to make its way through the system because of the extra inventory would result in waiting time at each machine. System B in this example is five times more responsive than System A if a changeover was to be scheduled.

Pull System

There are two basic ways to schedule a manufacturing operation. Either a Pull System or a Push System can be used. In a Push System, the release of raw materials into the manufacturing operation is controlled by a master planning schedule. This schedule is either constructed by a group of knowledgeable production planners, or, more fashionably, it is created by a computer running MRP (Materials Resource Planning) software. This software takes into account demand data as well as manufacturing lead time and inventory levels to create a daily plan. As might be expected, the output from a program like this is very sensitive to inventory data accuracy.

One of the goals of lean manufacturing is to create a system where the lead time is short enough to not have to resort to exotic planning systems. Pull systems are very simple in that they rely on a signal from a downstream operation to schedule production at an upstream operation. This signal may consist of an electronic message, a kanban card, or simply an empty parts basket. What makes a pull system work is that the upstream operation is responsive enough to supply parts in a short period of time. This may break down if the upstream operation has any time intensive steps such as heat treating. When this occurs a combination of pull and push is then used to control the system.

Level Production

To achieve level production short term variations in demand are smoothed out over a period of time (a week or a month), and production takes place at a constant rate over that period. This allows the production work team to become comfortable in their working patterns, and thus variation in the final product is minimized.

The concept of leveling does not stop only with production. Leveling can be applied to predictive maintenance tasks, gauging, and tool changes as well. This way, difficult and time consuming tasks can be interspersed with simple tasks to smooth out the indirect work flow as well.

Quick Changeovers

Quick changeovers are key to making a manufacturing system responsive because short change over times enable decreased run sizes. Traditionally, long changeovers were an excuse for running large batches of a product. A tradeoff between inventory holding cost and changeover time typically was used to calculate an “ideal” batch size. However, this type of rational becomes irrelevant when the setup time between products approaches zero. The typical goal for changeovers is to reduce the total time below ten minutes.

Quick changeovers also require a large amount of discipline. Quite often, a manufacturing team will make an effort to reduce changeover time only to find it creeping upward as time goes by. A conscious effort is thus required to keep changeover times down near their developed potential. The typical goal for changeovers is to reduce the time between the production of two different kinds of parts to under ten minutes.

Continuous Improvement

Lean manufacturing requires an enormous amount of attention being paid to *kaizen* – the continuous improvement of all aspects of manufacturing. Accordingly, workers need to be educated in problem solving techniques, and management should regard participation in the suggestion program as an important measure of the manufacturing system’s performance.

Visual Control

The use of visual indicators is used extensively in lean manufacturing. The kanban card mentioned above is an example of visual control applied to inventory management. Another key element of visual control is the “andon” board which signals quality problems with the use of flashing lights. A final example of visual control are the clear demarcations for everything from inventory placement to work station function. An outsider or a new employee then has a very clear picture soon after arrival of the work system layout and function.

Standardized Work

Each job is analyzed down to its constituent motions, and this sequence of motions is then refined for maximum performance. This optimization is done by the workgroup, and it is normally documented in clear view of the job. The goal is to have everyone that performs the job, across all shifts, to do it the same way. This consistency provides an insurance against mistakes, tracability to a root cause if there is a quality problem, and a solid basis for further continuous improvement of the job.

The combination of these physical systems and operating policies discussed above creates an extraordinarily disciplined organization capable of achieving high quality with low cost. In order to make each of these operating principles a reality, the production system must be designed to achieve these requirements. There are six specific design objectives that lean manufacturing systems must be based on to achieve the above operating goals.

2.3.2 Lean Manufacturing System Design Guidelines

The manufacturing design process blends customer needs (delivery, quality, etc.) with plant needs (material flow, space, ROI, etc.) to develop a design. Effective design processes turn these needs into system functional requirements. Functional requirements are then further decomposed into manufacturing system and machine specific design parameters as illustrated in Figure 2.3. There are several methods in industry practice used to decompose needs into functional requirements and design parameters. The two most useful ones are Axiomatic Design [4] and Quality Function Deployment [5]. The detail of these approaches will not be presented here, however, the results of using Axiomatic Design to a generic lean manufacturing system is presented below. These guidelines are general enough to work with any type of manufacturing system being designed.

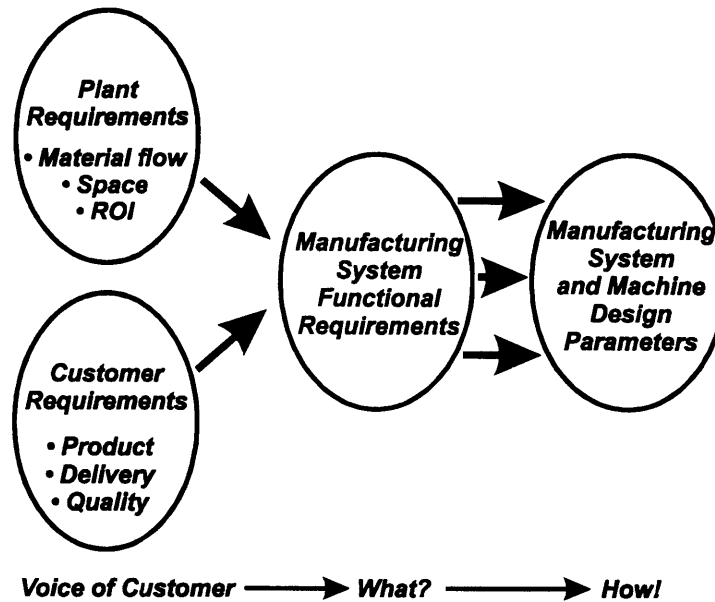


Figure 2.3. The process of mapping needs into design parameters.

Objective #1 - Achieve Volume Flexibility

Volume flexibility is the ability to scale operating costs with changes in production volume. In typical mass production systems varying volume can be impossible both physically and politically. For example, an assembly line, such as the one illustrated in Figure 2.4, is constrained because no matter what volume the customer is demanding, the line has very little flexibility in staffing to conform to that demand pattern because with a worker tied to every machine, staffing levels must remain constant regardless of volume. Ideally, if twice the number of products are ordered, the system should be designed to add twice as many people and build twice as many parts. In reality, many mass production systems have little flexibility in this regard. Job functions are typically very narrow, and each specific task is required to complete the machining or assembly of a product. Often, the same number of people are required to run the line regardless of what volume the customer is demanding. So called "Flexible Machining Systems" (FMS) often fall short in this regard as well. In theory, if demand drops for a product, FMS can simply reconfigure to make another product, but this is dependent on there being another product that can utilize that type of machine. If there is no other substitute, then it is possible that the

FMS, a very expensive asset, will be sitting idle. Lean manufacturing systems are designed such that volume flexibility is achievable through adding or subtracting the number of workers producing a certain product. Excess workers are utilized in cleaning, maintenance, training, or continuous improvement activities.

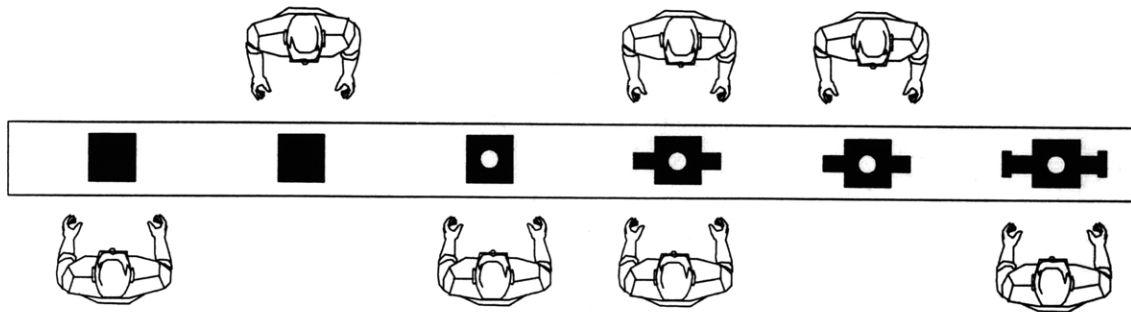


Figure 2.4. High division of labor. Operators perform simple tasks at fixed stations, thus, creating a situation where volume flexibility is costly.

One way of achieving volume flexibility is through the use of a lean manufacturing cell. Cells such as the one depicted below are volume flexible because as the demand rate varies, the production output can be adjusted by adding or subtracting workers. Figure 2.5 illustrates the use of work loops to accomplish this. Loops A through D depict the work patterns of a four member work group. If demand were to drop, then the job could be staffed by three workers, and the work loops would then be adjusted accordingly. That way, unlike Figure 2.4, operating costs can be adjusted with production volume.

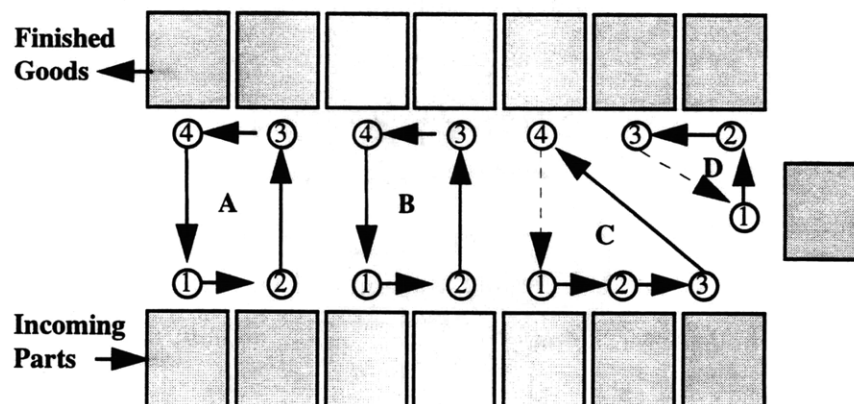


Figure 2.5. Volume flexible lean production cell [adapted from 6].

Objective #2 - Perfect Quality

The premise behind this guideline is that *quality is designed into the system*. Mass production systems often *sort* for quality, *repair* for quality, and *inspect* for quality. Lean systems employ the following guidelines to insure that zero defects leaving the manufacturing system is indeed a reachable goal:

- 100% mistake proofing of each machine. Also called by its Japanese term, Pokayoke, this design guideline says that if there is the possibility of making an error, that there will be sensors, devices, and fixtures designed to prevent possible defects from occurring. An example of such a system is shown in Figure 2.6. These systems can be as simple as a pin requiring that the operator set a part down in the correct orientation, and they can be as complex as a computer vision system. In a well performing lean system, the workforce often initiates the ideas behind error proofing mechanisms.

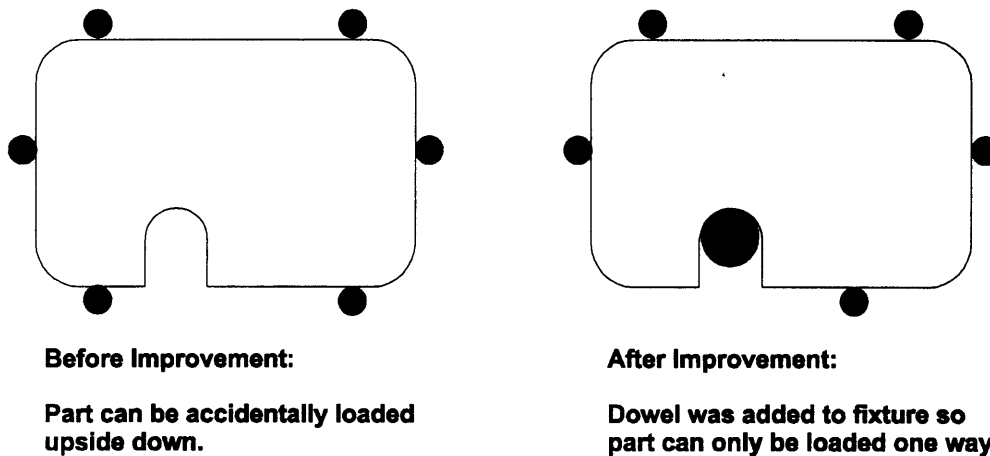


Figure 2.6. Illustration of an error proofing device.

- Defects are not advanced. Mass production systems advance defects and move them to a repair area. Lean systems require that the production system stops, and that all minor repairs are completed in-station. If a problem is too severe for in-station repair, then parts are taken to a teardown area for determination of the root cause.

- There are no repair loops. This is to insure that the incentives are aligned to follow the previous rule. It is often politically difficult to stop a production line, however, if the management and operators know that is the only option if there is a quality problem, then "doing the right thing" is easier.
- Every part must pass through every station. This rule is, once again, largely based on making sure that all parts are produced on the production line and not in a repair area. Historically, a large percentage all defects come from the repair bench because there are few standard procedures. This guideline ensures that all parts are produced by the same tooling, work practices, and error proofing devices.

Objective #3 - Undisrupted Production

There are many reasons that production gets interrupted: material handling, maintenance, cleaning, and changeovers to name a few. This design guideline focuses on creating a physical manufacturing system that minimizes all possibilities for disruption. Below are listed some specifics of how to accomplish this goal:

- In assembly, component parts should be fed from locations that are easily reachable by material handlers. This minimizes wasted motion, and most often results in less strain on workers.
- Vital control systems should be easily accessible. In the case that repairs or adjustments are required, the manufacturing system requires quick and easy access to mechanical, electrical, and software controls.
- Changeover time between models should approach zero. As previously discussed, quick changeovers are essential to having a responsive manufacturing system.
- Work stations should be designed with cleanliness in mind. In machining stations, chips should be fed to the rear of the machine for removal. On all machines, the design should not contain features that trap dirt, oil and grime.

Objective #4 - Proper Manufacturing System Capacity

Unlike the volume flexibility objective, system capacity is less concerned with the range of customer volume demanded and more concerned with what the maximum customer demand will be. The chief guideline to be followed here is that for each machine in the manufacturing system, its cycle time must be less than the lower range of the customer Takt time [6].

$$\text{Machine Cycle Time} < \text{Lower Design Range of Takt Time} \quad (1)$$

Important factors in machine cycle time include the specific manufacturing process, part clamping and fixturing methods, and the definition of the work content for each machine.

Objective #5 - Maximized Worker Productivity

From a purely physical point of view, maximizing productivity means reducing the amount of standing and walking time, minimizing walking distances, and balancing work loads between workers. Specific design guidelines that come from these objectives include reducing the width of machines as much as possible to reduce walking. For small component operations the rule of thumb is to have machines no wider than 4ft. There should also be no obstructions in walking paths, and in a machining or assembly area the layout should allow many options for work patterns to support volume flexibility. For lean systems that employ work cells, this guideline means that a worker should be running at least two machines in the loop even under the highest volume running conditions.

Objective #6 - Teamwork

The physical design of the work system can have substantial effects on the effectiveness of teamwork. Workers need to be able to identify problems anywhere in the system, and they need to be able to easily assist each other when problems arise. These guidelines require that the system be small enough so that everyone can see from end to end. It

requires that no one is physically isolated, and it requires that physical distractions, such as noise, be minimized.

2.4 Lean Manufacturing System Social Framework - Human Transition

As illustrated by the above design objective concerning teamwork, there exist many interrelationships between social and technical sides of a lean manufacturing system. If managed properly, the social transitions can be done in relative harmony with the technical changes that are taking place. One of the most important items on the social side is how different manufacturing job classifications will have to change, however, there are several other challenges as well.

2.4.1 Job Content Transition

As was eluded to in the section above, lean manufacturing systems have moved away from the old command and control management tactics of the (not so distant) past. This is partly due to the changes in measurables that are necessary, but mostly it is due to the realization that the best way to run a manufacturing system is to place the responsibility of running day-to-day operations with the workers who have a close interaction with the job. Thus, decision making is driven to the level where there is the most knowledge for making an informed choice.

This idea sounds completely rational, however, many companies find that implementation is difficult. What implementation requires is restructuring of what lower level management is responsible for. This often is viewed as a removal of power from management, and an increase in power by the workforce. If low level management is not ready to surrender some power, which they often are not, then there will be a struggle. As stated by Adler in his research on the NUMMI plant [7],

“...The key to NUMMI’s success is that management gave up some of its power, some of its traditional prerogatives. If managers want to motivate workers to contribute and learn, they have to give up some of their power.”

Below is a table that lays out what kind of transition each level of hierarchy should be expected to undergo during a lean transition:

Table 2.1. Job content transformation.

Job Transformations Moving from Mass Production to Lean Manufacturing		
	Mass Production	Lean Manufacturing
Production Workers	<ul style="list-style-type: none"> • Minimal scope of discretion • Little reliance on skills • Strive for stability 	<ul style="list-style-type: none"> • Have capacity to mobilize • Exhibit responsibility • Data driven and customer oriented • Work toward change
Skilled Trades	<ul style="list-style-type: none"> • Focus on fixing what is broken 	<ul style="list-style-type: none"> • Focus on preventative maintenance
Industrial Engineering	<ul style="list-style-type: none"> • Time studies • Work Standards development 	<ul style="list-style-type: none"> • Future manufacturing system design • Manufacturing representative on product teams
Management	<ul style="list-style-type: none"> • Command and Control 	<ul style="list-style-type: none"> • Coach • Change leader • Measurables champion

2.4.2 Challenges on the Social Side

Along with the job description changes, there are several other social challenges that come about through the changes in manufacturing system design. Some of the most pronounced ones include:

Job stress

Section 2.3.1 discusses the physical advantages of creating a close coupled, single piece flow manufacturing system. Quality, responsiveness, and space considerations are all improved, however, this responsiveness does not come without a price. In order for single

piece flow to work smoothly, operations A through D of Figure 2.3 need to be predictable in their output. Unlike System A, which has the luxury of inventory to keep the remainder of the system running if one machine goes down, System B shuts down entirely if there is a problem. In order for single piece flow systems to work, great attention must be paid to insure that machines do not break down unpredictably. Lean manufacturing has been likened to “management by stress” [7] for this reason. With no inventories in place to buffer problems, the workplace can become a very stressful environment when machines go down. Lean manufacturing equipment must be designed with reliability and maintainability in mind, and predictive maintenance programs must be effectively in place. If these things are done successfully, then the workplace has the possibility of becoming less stressful than in the days of command-and-control management. Once again, there is an important balance between the social and technical aspects of the system.

Increased Responsibility for Problem Solving

One of the most powerful aspects of lean manufacturing is that decisions are made at an appropriate level of hierarchy. For the factory floor this means that production workers, or more appropriately the production work team, will be making many of the short term, daily decisions that they traditionally would have left to their supervision. Examples of this type of decision making include the scheduling of work rotations, simple trouble shooting of machinery, and even line balancing.

Preparing production workers to take on these new roles and responsibilities requires a carefully planned effort and a large amount of patience on management's part. Decision making in critical situations is not something that most line workers in mass production plants have ever been a part of. Therefore, suddenly turning over this level of responsibility to a inexperienced and poorly trained work team will fail. The most successful efforts in this transition of responsibility are conducted over a period of time commensurate with the work team's skill level. At periodic points of the hand-off process, checkpoints are built in to act as reflection periods and gateways to turning over greater

amounts of responsibility [8]. Of course, training also plays an important role in the process. Training in lean manufacturing principles, roles and responsibilities, and technical issues is a critical aspect of a successful lean transition. Training and experience go hand-in-hand with handing off responsibility.

Teamwork skills

Teamwork is a natural part of lean manufacturing. It is not a natural part of mass production because with management making all the calls, there is no need for the production work force running a job to work together and make decisions or improvements to the system. Trying to foster teamwork in an atmosphere that has traditionally been hierarchical has several challenges. First, most effective teams have members that are cross trained in each job. In mass production, high division of labor creates very small skill sets that must be broadened during the transition to lean. Another challenge is improving the communication and interpersonal skills of work team members so that they can effectively solve problems together. This requires training and practice in conflict resolution, effective negotiation, and roles and responsibilities of the team. Finally, the teams need to discover how to manage their job, and this can only come through experience. The initial growing experience will take time. Companies are asking their production work force to play roles that are vastly expanded from what they are accustomed to. The increased responsibility and autonomy has proven to increase job satisfaction dramatically, but the transition period is usually difficult, and must be handled with a plan and with perseverance.

Balanced Work Loads

Section 2.3.2 discussed the advantages of maximizing worker productivity. This is especially true in high wage environments where a worker's time is expensive. One component of maximizing productivity is balancing work loads between workers, and this can present a challenge in traditional brownfield manufacturing sites. The bar chart below depicts a typical work load variation between fixed stations on an assembly line.

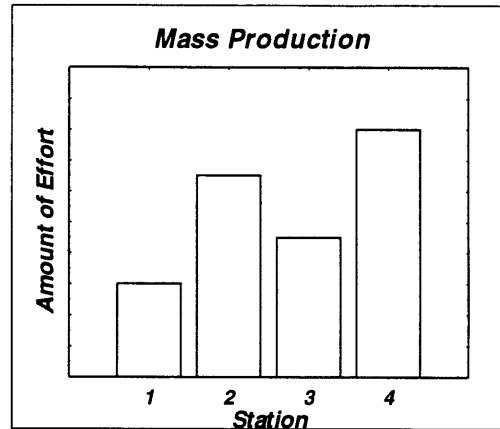


Figure 2.7. Mass production job effort variation.

The low effort jobs are highly sought after. These jobs typically go to older, higher seniority workers, whereas the high effort jobs are reserved for the younger, more energetic employees. With a lean manufacturing operation, continuous improvement efforts would work toward eliminating the low effort job (with that worker moving elsewhere in the plant or to a kaizen team) as shown in the next figure.

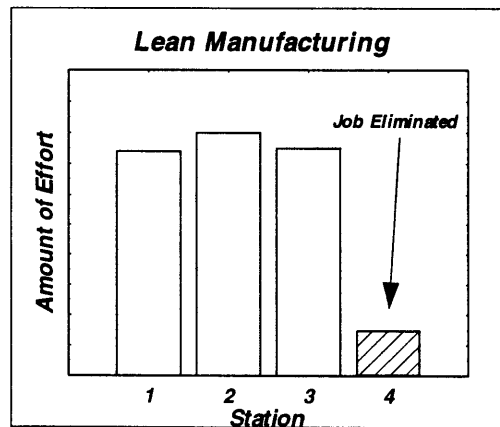


Figure 2.8. Lean manufacturing job effort variation. Station 4 is slotted for elimination through continuous improvement efforts.

Moving in this direction from a traditional plant culture where workers earn the easy jobs is a politically tough obstacle. Once again, this must be met with perseverance and properly set expectations.

Continuous Improvement

Bringing the workforce to view change as an opportunity for improvement instead of a disturbance is a challenge. Lean manufacturing requires that people constantly improve their work environment, and that means that everyone is at least comfortable with change, and ideally views change as a standard method of operation.

2.4 What Happens when the Social and Technical are out of Balance? -- Some Examples

The previous sections illustrate the extent of change necessary from both the social and technical sides, and they illustrate that there is a dependency between these two aspects of the transition. There are many examples in recent history, the following case studies being only two, where there existed an imbalance between the social and technical sides of a move toward lean manufacturing.

2.4.1 GM/Suzuki CAMI Plant

In 1987, General Motors and Suzuki entered into a joint venture to build small sport utility vehicles at a greenfield site in Ontario Canada. The best plants on the North American continent (Georgetown and NUMMI) were benchmarked to provide CAMI with a state of the art system to build vehicles. The assembly system at CAMI took many design cues from the benchmarked facilities with a resulting assembly system *design* which is state of the art. However, the vehicles that are produced at the plant don't come close to meeting the cost and quality targets that Georgetown and NUMMI do. Even worse, the plant has had periods of great labor unrest. In the Fall of 1992 the Canadian Auto Workers (CAW) staged a five week strike to protest stressful working conditions. Many of these issues were thought to directly emanate from the lean systems that had been put in place.

What is obviously missing here is the ability of the workforce to run the job as intended. A key issue is lack of training. According to one account, workers received very little training [9], and "much of it is ideological indoctrination." According to a Ford

executive, who received information through a consulting company that is used by both GM and Ford, “CAMI had the physicals right, but it is all a charade. They never engaged the workforce, and that is the key to doing lean right.”

2.4.2 The Ford Production System

Situations also exist where the technical side has been given relatively less attention than the social side. One of the key themes in the initial implementation plan for the Ford Production System (FPS) is the development of workgroups. These workgroups have more responsibility for running day-to-day operations, and they are tasked with simple maintenance, developing work schedules, and on-the-job troubleshooting. Some workgroups are struggling as the FPS roll out takes place because their performance as a team is being hindered by the physical work system that they are responsible for running. For example, ad hoc problem solving as a team is difficult if the workgroup is separated from each other and cannot communicate. Many of the old mass production operations work on the “one man, one machine” philosophy, and there are instances where workers are literally hidden from each other on the job. How then, if the production workgroup does not build parts as a team, can they be expected to function as a team? Getting together once per week for a workgroup meeting does not replace working together on the floor, and evidence indicates that many of these workgroups, put into place to run old mass production systems, do not exhibit good team skills on the job (such as problem solving). Work systems must be designed so that the workgroup can function as a team.

These two cases show, therefore, that not addressing the interrelationship between the social and the technical aspects of implementing lean manufacturing can lead to sub-optimal performance, and in some cases like CAMI, complete system failure. If the transformation is biased from the social perspective, and the addition of workgroups is done without a corresponding change in technology, then the only benefit may be some incremental advantage by creating skills and awareness that workers have not previously had. There is no guarantee of better manufacturing system performance because the system design could be constraining improvement. Conversely, if the transformation is

too heavily biased with a technical perspective, and systems are launched without new management practices and full capability and buy-in of the workforce, then this can lead to sub-optimization and failure as well. For example, in some assembly operations, like vehicles, where the layout of a lean system is similar to mass production, Womack points out that “lean production will revert to mass production.” [1, pp102-103] In other lean operations, such as manufacturing work cells, the system is more fragile. In these environments the fragility stems from both the lack of inventory buffers, and from the very nature of lean work requiring that workers try hard and take on more responsibility such as trouble shooting and minor maintenance that before were not a part of their job responsibilities.

2.5 Conclusion

The challenge, then, is to somehow balance, coordinate, and leverage the social and technical aspects of lean manufacturing throughout the design and launch process. This is especially important when attempting to transform a traditional mass production brownfield site. Chapters three and four present a case study of one such transformation. This case attempts to illustrate one method of going about trying to integrate social and technical aspects of a manufacturing system launch, and it discusses the advantages and disadvantages of that approach.

3. A Case Study in the Design and Implementation of a Lean Manufacturing System

3.1 The Silverton Plant

Silverton was one of Autoco's oldest and largest components plants. It was built in the mid 1950's, and some of the machinery dated back to the 1930's. The plant produced components for rear wheel drive vehicles, but there was enough volume and product variation to take up almost 3 million square feet of floor space. Silverton employed nearly 4000 people, and over 3000 of those were proud card carrying members of the United Auto Workers union.

The booming Sport Utility Vehicle (SUV) and truck markets placed great demands on Silverton's old production machinery. In the 1980's, the auto industry held a collective notion that many rear wheel drive vehicles would be phased out within the next decade, and this led to the Silverton plant being last on the list for any capital investments. What resulted was a plant that was under capacitized, and more importantly unable to handle the current levels of product variation. The result was a highly stressed system that required a high overtime budget in 1997 to meet customer demands.

The management structure at Silverton was very traditional with department boundaries being drawn on a functional basis. There were separate Business Units (BUs) for each sub-component part and an Assembly BU. The Assembly BU was considered the customer of all the component BUs, and each BU was responsible for their part of Silverton's entire product lineup. When Assembly was through with their part of the process, they shipped their product to a variety of different vehicle plants around the world. The figure below illustrates Silverton's value chain as it was in 1997.

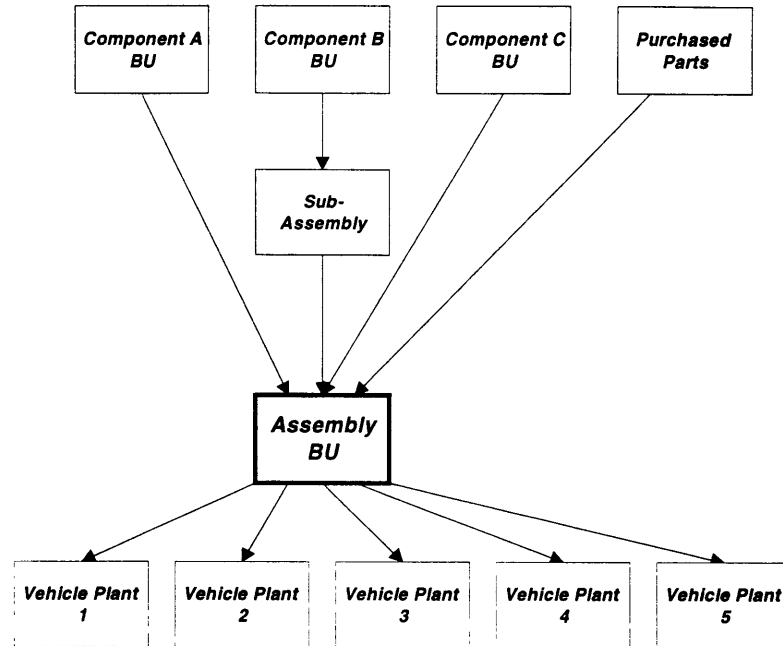


Figure 3.1. Silverton business unit structure.

The current management of Assembly was committed to moving Silverton's antiquated mass production framework to a more modern lean manufacturing one. This would require updating some of the equipment currently used in the plant, and it would mean that production employees (hourly and salaried) would see great changes in how their working days were spent.

Most of the assembly operations were conducted in Department 17. This department had all of the traditional characteristics of a mass production operation:

- A fast moving assembly line.
- "Push" scheduling practices.
- A large number of workers whose tasks were simplified and subdivided down into small chunks of work that could be accomplished within an eight second time frame.
- A rack out area for defective parts at the end of the line.
- Complex tooling required to support short cycle times.

- Traditional supervision who's concerns were mainly tracking down people to staff the work stations, and tracking down various parts that were in short supply or missing.
- A "Labor and Overhead" task of reducing costs between 5% and 10% each year.
- Inspectors who's jobs were dedicated to catching the mistakes of others.

In addition, the product complexity and volume in Department 17 had risen dramatically in the last several years. New vehicles had been introduced that used the Silverton product, and also, the number of variants of the older products had increased. What resulted was seven different product families being run down the same line. Within these families there were almost 60 different product variations. Overall volume had risen 15% over the last five years.

Assembly complexity varied between families as well. Some families would only require about 90 people on the assembly line, while other more complex ones would require as many as 125 people. An attempt was made to split the high and low complexity components between shifts and staff each shift accordingly, however, this was difficult because the arrival of sub-component parts from the other business units was often very unpredictable. This unpredictability resulted in short production runs of each family, and furthermore, in a complex task of employee reassignments whenever a changeover took place. During the Summer of 1997, a supervisor had to reassign an employee every 3.4 minutes on average to keep the line running.

In addition to employee reassignments there was the task of making sure that the correct parts were line side when a changeover took place. With over 35 components needed, a flurry of forklift traffic was necessary to keep the correct parts in the correct places. This traffic was disruptive, potentially dangerous, and often confusing. Therefore, material handling concerns coupled with the complexity of worker assignments caused the line superintendent to work diligently toward long production runs. Long runs added considerable stability to the system, and in turn improved quality, worker moral, and throughput.

3.1.1 Silverton Quality

It was common knowledge within Autoco that Silverton's quality wasn't as high as it should be. Quality was improving (Figure 3.2), and in some products quality levels were as good or better than the competition. In 1997, seven of ten component families had best-in-class quality at some point throughout the year. However, when compared to other automotive components with equal or higher complexity, it was obvious that Silverton was lacking. Quality was the main driver toward moving to more robust and predictable manufacturing methods.

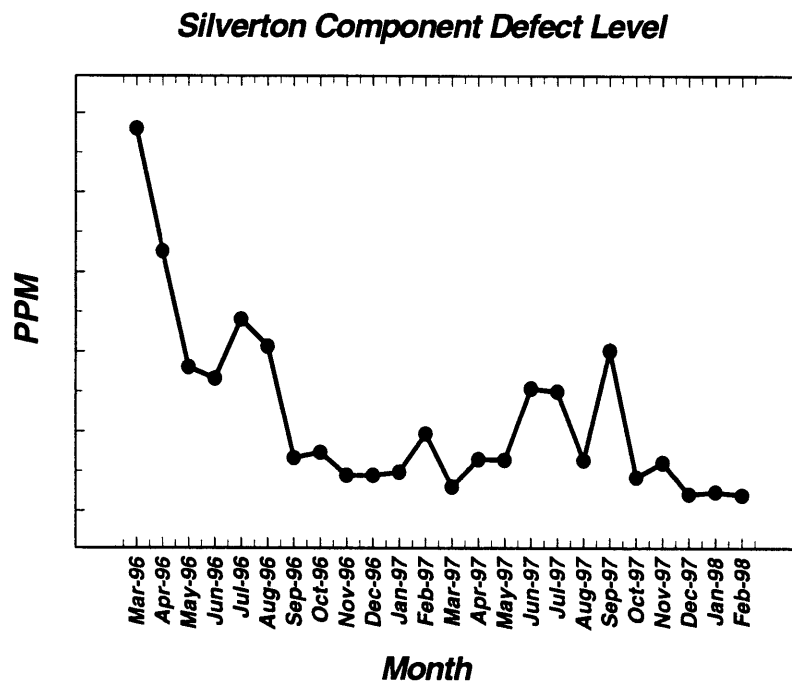


Figure 3.2. Silverton outgoing defect rate in PPM (Parts Per Million).

Silverton's product affected overall vehicle quality in two basic ways: through its function, and through any perceptible noise it created in the driver compartment. Function was a straightforward issue; an area that Department 17 could make a large impact on. Noise, on the other hand, was more complex. The interrelationship of Silverton's product with the vehicle was often difficult to sort out. There were often long drawn out debates over whether a noise issue was Silverton's fault or the fault of some other part of the

vehicle. Most often this answer took a long time to resolve, and by the time it was, many thousands of components had been shipped. To further complicate matters, vehicles were becoming quieter with every model year. As wind noise and road noise became less perceptible, component noise became more of an issue. This created a heightened awareness of Silverton's product with each new model.

While noise issues were important, it was the functional issues that Department 17 had the most control over, and functional issues were affected greatly by component assembly. Department 17's current quality processes revolved around inspection and repair. Repairs were so prolific that the space dedicated for the them was almost one quarter of the area dedicated to production. If a quality issue was spotted anywhere along the assembly line that component was flagged and offloaded into a repair rack. When a rack was full it was transported by a forklift to the repair area. Racks could fill up very quickly. As one superintendent put it, "At this line speed, a five minute problem results in a big pile of parts."

This process resulted in a substantial number of components going through the repair area every day. Nearly a half hour of production went into the repair area each shift – as many as 200 parts. As has been documented in other cases, controlling quality of repaired parts was very difficult. In general, there was a lack of organizational and process discipline. The repair group worked independently and was responsible for several different families of product. The result was that over 60% of Silverton's quality problems came directly from the repair bench.

Furthermore, the quantity of repairs was difficult to reduce. The line moved so fast there was never a chance to do any in-station repairs, and it was difficult to catch quality problems with supplied sub-assemblies. In 1997 the PPM (parts per million) quality level of incoming parts was worse than the assembled component that left the line. Department 17 was actually acting as a filter for their suppliers while at the same time working to reduce the number of errors that they introduced into the product. This was accomplished through a large inspection effort (up to 8% of the people on the line were dedicated

inspectors) and through implementation of the "positive buy" process. Positive buys were colored ink dots that indicated a certain operation had been completed and inspected for. At the end of the line, the components often looked like pieces of modern art because of all their multi-colored marks. Inspection and positive buys were a step forward in assuring quality, however, functional assembly problems were uncovered in the field even when positive buy marks were present. Silverton management realized that positive buys were a partial fix for bigger problems associated with the manufacturing process. As a former superintendent put it, "Today we build 'em, ship 'em, and pray."

3.2 Opportunity to Implement Lean Production

This situation presented an opportunity to change the way that Silverton manufactured its product. The new management of the Assembly BU knew that drastic changes in the process were necessary. Now matter how well production management performed, quality levels were constrained by the process. As long as the line speed was high, and the repair area was used to catch problems, there would be quality issues. As the new assembly manager put it, "Right now our guys are playing goalie. We are asking them to work harder to produce higher quality, but we haven't done anything to reduce the shots on goal. In fact, today it's even more difficult with the added complexity. We don't need better goalies, we need to play the whole game better. We need to reduce the shots on goal."

The manager of Assembly knew that the only way to do that was through a transformation of the process from traditional mass production, with its secondary emphasis on quality, to a leaner system, where the work systems are designed around the elimination of defects. This transition was going to be very difficult because the current culture and state of knowledge in the plant was aligned firmly behind mass production practices.

The philosophies of production floor management were rooted in command and control (one production supervisor stated it as, "My job is chasing people and parts."). There

were some efforts in place to get input from production workers on system improvements, but these were not very fruitful. The EI sessions² had turned primarily into forums where worker comfort and ergonomics issues were addressed, however, floor management did not view them as productive in improving product quality or throughput. Therefore, the expectation of the production workforce to have any useful input into manufacturing processes was small. There did exist a small number of hourly workers that took it upon themselves to supply management with feedback, but these efforts were rare, and the process was not institutionalized.

Likewise, the production engineering department was only just beginning to learn about the design of lean manufacturing systems. This group prided itself on its ability to conceptualize and develop high speed production machinery that had high throughput capabilities. All of these systems were engineered and built by a set of vendors that had served Silverton with automated solutions for many years, therefore, the vendors had little experience with lean manufacturing either. Automated solutions were seen as a way to “reduce heads”.

Even with all these factors stacked up against the transition to lean manufacturing, there still existed several aligning factors that contributed to making a transition in how Silverton manufactured its product. These included:

- Management support and expertise. New management had expertise and experience in lean manufacturing. They served well as initiating sponsors, and they were a set of fresh eyes on an old system.
- The promised quality of moving to a lean system alone was worth it for everyone involved. Even if they were skeptical about the soft side of lean manufacturing, they saw the quality potential and that was enough to align them.

² Employee Involvement grew out of benchmarking Japanese Quality Circles. These sessions were an attempt to draw on the tacit knowledge of the production line workers to improve the production system.

- The plant was moving from a cost center to a profit center, and this put a lot of pressure on managing total costs. Just looking at labor and overhead wasn't good enough anymore. Management now had to look at the whole system because that is what they were going to be evaluated on.
- The current system was extremely difficult to manage – not only were the quality problems hard to deal with, but scheduling and maintenance concerns took inordinate time and had considerable costs. The current assembly scheduling system was done completely by hand. The person responsible for scheduling arrived at 2:00am to complete the schedule by the start of Shift 1 at 6:00am. This schedule was modified on-the-fly several times during the day to account for mis-counts, part shortages, and quality problems.
- The UAW was ready for change. Union leadership knew that the current system needed to be changed, and they were proactive in helping to select the work team and keep everyone on track.
- A new luxury car was being launched, and the opportunity was seized to showcase lean production around this new product.
- Silverton's customers were very interested in any new process that would insure higher quality.

These factors all conspired to enhance the probability that change would happen. One method of placing a framework on this probability is to organize the forces of change into Equation 2. This model (modified from [10]) suggests five variables that effect change:

- D – dissatisfaction with the current state of affairs
- CR – the cause of any resistance to change
- M – the Model of the final change state (the clarity of vision among all involved)
- O – any Outside influences that will have a positive effect on change
- I – how successful the implementation is

These variables are combined to offer the following model for change:

$$\text{Probability of Change} = D \times \frac{1}{CR} \times M \times O \times I \quad (2)$$

The structure of this model suggests that all of the listed factors are of equal importance, and that if any one of them is missing, that change will not happen effectively. The examination of each variable suggests that Silverton has everything aligned to effect change *if* implementation is done properly.

Dissatisfaction: There was much dissatisfaction with the current system. Quality issues were the number one concern, but high costs and the increased complexity of running Department 17 were also factors.

Cause of Resistance: There were two possible CR's at Silverton, 1) Resistance within the ranks of middle management to surrender some power to the workforce, 2) Resistance by the workforce to take on more responsibility for their daily work tasks. Both of these causes can be mitigated by successful implementation and a strong change model.

Model: An overall awareness of building a shared vision was with the project from the start. Everyone knew that a better way of doing things existed, and through daily launch meetings, offsites, and other team building activities, this vision solidified over time. One area that could have been handled better was lean manufacturing training of the manufacturing engineering staff. The Assembly BU manager stated it like this, "We haven't exposed Silverton to ten percent of the lean training we need to. We've been remiss there. Lean is an unclear suggestion to the Silverton team. We need to clearly define it."

Outside Influences: There were strong influences from customers and upper management alike for success on this project. This line was seen as a model that the rest of the company would follow, therefore, upper management was very interested in a positive outcome. Customers, as well, were very interested in improved quality.

Implementation: The history of lean implementation efforts at brownfield sites has shown mixed results because of the simultaneous infusion of new technology and new work rules. Implementation was viewed as a key success factor at Silverton.

This focus allowed the plant to act quickly. A new department was created around the luxury car product family, and plans were formulated to design and implement the new production system.

3.3 Implementation

The implementation plan centered around three strategic decisions: 1) the assignment of a full time launch coordinator to the process, 2) the assembly of a cross functional launch team that consisted of representatives from Industrial Engineering, Process Engineering, Safety, Production, Process Leadership³, and management, and 3) the development of a comprehensive launch plan that captured the social and technical agendas in a single framework (to be discussed in detail in Chapter 4).

This approach to implementation was much different than how the process had traditionally been approached at Silverton. Table 3.1 illustrates the differences in how this launch was run compared to those in the early 1980's and the early 1990's.

³ Autoco formed a process leadership group as a means of developing and spreading best practices throughout the company.

Table 3.1. Launch implementation at Silverton.

	Early 1980's	Early 1990's	New Launch
Launch Responsibility	Engineering Department	Engineering Department with launch coordinator as shuttle diplomat	launch coordinator with cross functional team
Measurement of Project	ROI, Labor and Overhead savings	ROI, L&O, Quality	ROI, lean measurables
Consideration of Social Implications	"reduce heads"	Job security important – U.A.W. as stakeholder	explicit consideration of social and technical coupling
Training	very little	quality training sequential with launch	104 hours mandatory (lean, team, maintenance, dispute resolution, etc.)
Quality Attitude	<ul style="list-style-type: none">• no Statistical Process Control (SPC)• no machine runoffs• no control plans for quality	SPC/runoffs/control plans	zero defect mentality <ul style="list-style-type: none">• in-station process control• error proofing
Production Team Selection	favorites picked	Interview & record check process ("Best in Class")	surveyed for interest from Department 17 based on seniority

The migration of launch responsibility from the Engineering Department to a single launch coordinator who led a cross functional team is a symptom of the realization that manufacturing technology is one part of a larger complex system. The team approach was viewed as both a way to ensure that the system met, or at least addressed, the requirements of the stakeholders and as a means of communicating the progress of change throughout the plant.

The change in quality attitude was a reflection of the evolving quality movement. From the poor understanding of quality in the early 1980's to the SPC dominated system designs of the late 1980's and early 1990's to the zero defect mentality which exists today, the attitudes toward how quality is defined have strongly impacted manufacturing system design and operation. For example, the decision was made early on that no faulty components from the line would be sent to a repair area; all repairs would be conducted before the component was removed from the line and placed into shipping dunnage.

The integration of social and technical components of the launch was also an area that underwent large change throughout the years. In the early 1980's and even into the 1990's

the main consideration of any new manufacturing system was to reduce headcount. This stemmed primarily from the measurement system that placed a heavy importance on labor costs. For the new line, a different perspective on labor was taken. Under the new system, labor was seen as an integral and important component of the complete manufacturing system, therefore a social as well as a technical agenda for the launch process was developed. Moreover, the coupling between social and technical components was explicitly addressed in the planning and execution of the launch.

What resulted was a manufacturing system that would look and perform much different than anything that currently existed at Silverton. This system would cost less, utilize labor more efficiently, be more responsive to customer needs, and produce with higher quality than any other component line.

3.4 Line Results

At the end of this study the line was just about to launch. Equipment was installed, the workgroup was in place, and a majority of workgroup members had been through basic skills training. The results depict the launch process up to, but not including, the actual production of parts. It is unfortunate that the timing of the study could not include several months of post-launch data, however, the project was to a point where there was a high level of confidence in it being successful.

The results are broken up into two main categories: line design results and analysis followed by an analysis of the launch process from the perspective of interview data. The design section will critique how well the launch team met the lean design guidelines presented in Section 2.3.2, and it will discuss the choices that the launch team made when deciding not to explicitly meet certain guidelines. Results on cost and projected performance in accordance with lean measurables are also included in this section. The analysis of the launch process is an amalgamation of survey and interview data that attempt to capture key successes and failures throughout the process. Much of this material is the basis for the change model presented in Chapter 5. Finally, an overall set

of lessons learned from the project is presented. These conclusions attempt to cut across design results and language data and present an integrative outlook on the interim success of the project.

3.4.1 Design Results

A general line layout is shown in Figure 3.3. This layout shows the assembly portion of the line, but it does not show any of the welding equipment. Notable in this layout is the use of individual build carts. A team of two workers follows a cart through the assembly process. The carts will travel down one of two separate build spurs, and each spur has six stations where the cart stops and the team completes any operations designated for that station. Each team of two is responsible for building up the entire product from start to finish. If there are any quality problems, there is a choice of doing a repair in-station if it is simple, or more complicated repairs will be taken to the tear down loop. In the teardown area the part is completely disassembled. A root cause for the problem is determined, and if the part is repairable, the same team follows the axle through the build process once again after removing defective components or making any necessary repairs.

The pace of the work is ultimately controlled by the individual work teams, but an andon-type light system is used to indicate to the team when the build cart should advance. For safety reasons, the cart will not advance until both members of the build team are out of the pathway. Cycle time is balanced between each of the work stations at about 40 seconds, and standard work procedures are planned for each step in the build process.

Volume flexibility on the line is achieved by adding or subtracting two person build teams. Mix flexibility is easily achieved because the line concentrates on only a single product family. The family had seven different variants, however, the maximum changeover between any two part numbers is about eight minutes. Most changeovers are immediate requiring no extra time or effort. The long term vision for Silverton is to build several of these lines for each different product family.

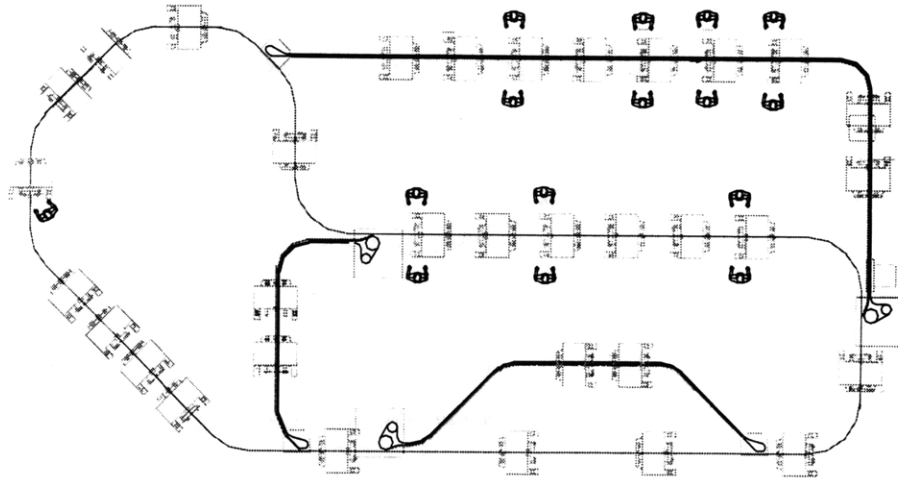


Figure 3.3. New line layout.

3.4.2 Adherence to Design Guidelines

Table 3.2 illustrates the lean line's adherence to the guidelines presented in Chapter 2. The first column presents the lean design objective, the second column presents generic design guidelines, and the third column illustrates the enabling design features of the new line [6]. This column also depicts where the design, for various constraining reasons, did not meet the objective specifically. These design issues are presented in italics.

Table 3.2. Lean design objectives, guidelines, and enabling factors for the new line.

Design Objective (What)	Design Guidelines (How)	Lean Line Enablers
Volume Flexibility	Vary number of workers	Add or subtract two-person work teams
Perfect Quality	<ul style="list-style-type: none"> • 100% mistake proofing of each machine • No repair loops • Defects not advanced • Every part passes through every station 	<ul style="list-style-type: none"> • Air hoist lock out for defects (RF tag tracks proper build) • Lube fill measurement head • DC torque guns w/feedback • Shaft separator tool • In-station repairs or disassembly in teardown loop • Test machine
Un-disrupted Production for: <ul style="list-style-type: none"> • Material handling • Maintenance • Cleaning • Changeovers 	<ul style="list-style-type: none"> • Components fed from location easily reachable. • Vital controls and systems easily accessible • Changeover time between models approaches zero • Stations designed with cleanliness in mind 	<ul style="list-style-type: none"> • <i>Operators must unload empty kit and load full kit at back of line.</i> • Lube fill will eliminate splashing, no painting of part, matting on line will be smooth for easy cleaning. • changeover time ~5min.

Proper Cell Capacity	<ul style="list-style-type: none"> • Machine cycle time < Lower range for takt time • Cycle time for manual assy. falls in the range of 40-60 sec. • Minimum volume meets space and investment efficiency targets 	<ul style="list-style-type: none"> • Takt time = 34 sec/unit. • ~35 sec. in station will allow defects to be repaired (vs. 7 sec on current line)
Maximized Worker Productivity <ul style="list-style-type: none"> • Standing/walking • Minimize walking distance • Balanced work loops 	<ul style="list-style-type: none"> • Manual station cycle time \leq (Takt time/X); where $X > 2$ • Width of machines < 4 feet • No obstructions in walking path • Cell layout allows many options for work loops 	<ul style="list-style-type: none"> • Teams follow assy. from start to finish - assy. is almost entirely manual, therefore, little opportunity to run > 1 machine. • <i>Test machine may obstruct path</i> • Build stations placed 6 ft. apart - this is as close as possible with size of part and kit
Teamwork <ul style="list-style-type: none"> • Workers can identify problems elsewhere in the cell • Workers can easily assist other workers 	<ul style="list-style-type: none"> • Each worker can see each operation • No workers are physically isolated 	<ul style="list-style-type: none"> • Assembly loop affords view of all operations, however, <i>operators on welder are obstructed</i>

As the comparison with the above guidelines show, this manufacturing system does not meet every requirement for being lean. It is actually a cross between lean manufacturing and a sociotechnical work system. It fits a lean model because the assembly process produces at the customer's Takt time, is mix flexible, is volume flexible, utilizes teamwork for trouble shooting and continuous improvement, and it is capable of producing perfect quality. It falls short of being truly lean because direct labor productivity is not maximized. A tradeoff has been made in productivity for implementing a more humanistic approach to job content [11]. This sociotechnical work system approach attempts to maximize learning and job content. Learning is increased because a two-person team follows the part through the system from start to finish. If there is a quality issue, the team receives immediate feedback, and they must correct their own mistakes before the part can be shipped. Increased job satisfaction is derived through ownership of building a part from start to finish. Shortly after launch, one worker was quoted as saying, "I wish I could put my signature on every part that I ship⁴."

⁴ In fact, in another plant at Autoco, there is a similar assembly system for building engines, and the workers actually *do* get to sign the final product. This engine line, running for over two years, has been quite successful. Quality levels have been high, and added flexibility that the design affords has given Autoco much latitude in scheduling special builds and in experimenting with niche products.

This system also places more responsibility on the individual worker to be knowledgeable about work processes and procedures. Unlike mass production, where jobs are simplified to the point of requiring very little training, and lean manufacturing as defined by the Toyota Production System, where the standard work cycle is usually limited to under one minute, the workers in this system are required to know six standard work procedures at each consecutive build station. This added complexity, illustrated in Figure 3.4 is also indicative of a sociotechnical work system.

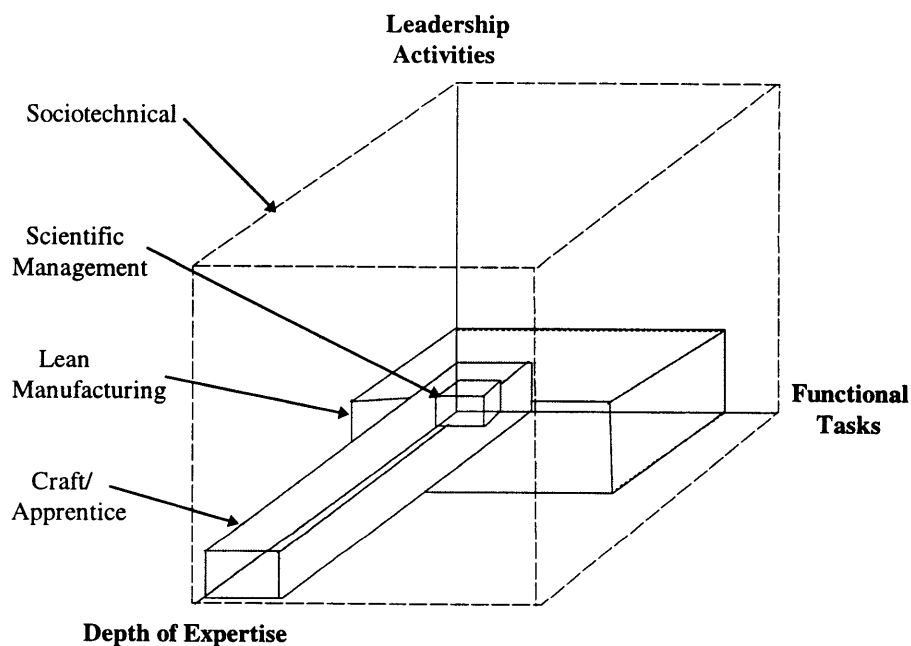


Figure 3.4. Comparison of job design models [12].

However, there is no fixed rule that mandates that the line must continue to operate in this fashion. If management and the workgroup decide that the increased efficiency of staffing the job differently is a worthwhile tradeoff of not having a pair of assemblers follow the part all the way through the process, then the system can move in that direction. For example, it is possible to develop a pair of balanced work loops that have some workers

operating the first three stations and another group operating the last three stations. This would eliminate some of the waste in walking with the arguable tradeoff of losing some ownership in not completing the total assembly.

3.4.3 Cost

Lean manufacturing systems attempt to minimize the total cost of building a product. One of the large areas for leverage during the design of a system is initial investment costs. There is an often cited misconception that building a set of focused lines will result in higher overall investment costs than a single flexible, high speed line that can incorporate all products. The analysis below in Table 3.3 refutes that claim for this application. The main reason for this is that high speed assembly operations require complex equipment to be able to assemble a variety of products. For example, there is a cover plate installation process that requires running down ten bolts. On the high speed line in Department 17, a ten head bolt gun is used to accomplish this task. This “10-way” is a very specialized device that costs nearly four times the amount of the simple hand nut runners on the new line. The expense of the main line is also increased because a backup gun is needed for each different bolt pattern.

There are other cost reductions on the new line that aren't as easily quantifiable. Quality impacts are one such example. A simple quality projection based on warranty data only touches the surface of what the cost of poor quality is. The process that Silverton went through if a quality problem was found by a customer was to first determine the root cause and develop corrective action. When this process was complete a member of management, usually a superintendent, would schedule a trip to the customer. On the agenda was a perfunctory tongue lashing followed by a presentation on how the problem would never happen again. What is the cost of such an exercise? The plane tickets and hotel accommodations are easy to calculate, but what about the cost of a key employee being away from the plant? What is the opportunity cost of them not being there if a critical situation were to arise? What about the cost of them spending their time ‘fire fighting’ rather than planing and executing longer term improvements? What is the cost

of lost goodwill and a lack of trust from the customer? None of these things are easily quantifiable, however, they all are real costs, and their magnitude may be as large as the costs that can be easily accounted for.

Other real but hard to quantify costs include engineering support, poor maintenance practices, and resources spent scheduling complex operations. Lean systems attempt to address each of these issues, however many of these benefits need to be taken on faith until after the systems are launched and true total cost figures can be calculated.

Table 3.3. Investment cost comparison between old and new manufacturing systems.

Station	Main Line				Lean Line			
	Line Items	Qty.	Cost	Total	Line Items	Qty.	Cost	Total
One	main unit	1	6,500,000.00	6,500,000.00	hand operated unit	2	110,000.00	220,000.00
	subtract test unit	3	(60,000.00)	(180,000.00)				
	subtract target robots	2	(100,000.00)	(200,000.00)				
				6,120,000.00				220,000.00
Two	two-spindle fixture	4	3,316.00	13,264.00	two-spindle fixture	4	3,316.00	13,264.00
	engineering	1	2,250.00	2,250.00	engineering	1	2,250.00	2,250.00
	DC motors	8	5,000.00	40,000.00	DC motors	8	5,000.00	40,000.00
	torque pack support	4	250.00	1,000.00	torque pack support	4	250.00	1,000.00
	torque arm	4	1,300.00	5,200.00	torque arm	4	1,300.00	5,200.00
	controller	2	36,000.00	72,000.00	controller	2	36,000.00	72,000.00
				133,714.00				133,714.00
Hand tools	same				same			
Three	pulse gun	1	10,000.00	10,000.00	DC gun	1	4,600.00	4,600.00
	backup	1	500.00	500.00	extra cord	1	655.00	655.00
	suspension system	1	1,500.00	1,500.00	suspension system	1	1,500.00	1,500.00
				12,000.00				6,755.00
Four	moving lube fill station	1	500,000.00	500,000.00	stationary lube fill station	1	100,000.00	100,000.00
Five	RTV station	2	85,000.00	170,000.00	CNC single station	1	30,000.00	30,000.00
	55 gal drum pumps	1	17,000.00	17,000.00	manual backup hardware	1	16,000.00	16,000.00
	part presentation hdwr.	2	1,700.00	3,400.00				
	misc. hardware	2	4,000.00	8,000.00				
				198,400.00				46,000.00
Six	10-way bolt guns (+backup)	4	100,000.00	400,000.00	DC guns	5	5,000.00	25,000.00
	suspension	1	5,000.00	5,000.00	controllers	4	7,000.00	28,000.00
				405,000.00	alarm box	2	1,500.00	3,000.00
Assembly line	main line hardware	1	3,000,000.00	3,000,000.00	lean line hardware	1	700,000.00	700,000.00
Material handling	tilt/lift tables	12	5,000.00	60,000.00	kitting	1	200,000.00	200,000.00
	racks etc.	10	2,000.00	20,000.00				
				80,000.00				200,000.00
Total				10,449,114.00	1,474,469.00			
Corrected for Volume				10,449,114.00	8,065,345.43			
Volume correction factor:				5.47				

23% Reduction

3.4.4 Projected Measurables Improvement

A comparison of lean measurables on the main line vs. the new line is shown in Table 3.4. The enabling factor in meeting the perfect first time quality goal is implementation of in-station quality control. If a problem is uncovered during assembly, the work team has immediate responsibility and authority to fix the problem. In the case that the problem is too large to fix in-station, the team directs the component to the teardown area where it is completely disassembled and rerouted through the entire build process once again. The build team does not give up possession of the part until it is assembled correctly and passes all of its tests. System Throughput Time is reduced primarily because of single piece flow through the welding and assembly process. This number could be reduced even further when the business units that supply to the Assembly BU do so in a pull fashion. Currently none of the supplying processes are lean enough to be able to do that, thus, inventory levels drive throughput time higher than ideal. Equipment efficiency has been improved slightly, however, this metric has diminished importance in the new system where the capital asset value of equipment is lower than that of the old mass production arrangement. Finally, building to a specified schedule should be much easier to accomplish on a system dedicated to producing components for only one family. Changeovers are simple, thereby making schedules with small batch sizes easy to follow.

Table 3.4. Lean measurables comparison.

	<i>Current Department 17</i>	<i>Lean Line Potential</i>	<i>% Change</i>
<i>First Time Through Quality</i>	94%	100%	6% <i>improvement</i>
<i>System Throughput Time</i>	21.4 hours	6 hours	72% <i>reduction</i>
<i>Equipment Efficiency</i>	94%	99%	5% <i>improvement</i>
<i>Build to Schedule</i>	93%	100%	7% <i>improvement</i>

3.5 Launch Process Results

Also important in understanding the overall results of the launch is an evaluation of the process. Included in the planned launch process were two feedback sessions. These sessions allowed the team to reflect on successes and failures, and they acted as a self correcting mechanism to get the launch process back on track if necessary. Included in the first feedback session, conducted in mid-November, were the results of a survey. This survey was given to all of the key members of the launch team including management, engineering, launch coordination, and production team personnel.

One of the highlights of the survey was a series of questions that inquired about program timing. The theme of the questions was to ask why certain planned milestones were not met. The last question asked the interviewee if they thought the program was going to meet overall timing, and then further inquired about the main reason why timing would or would not be met. Each question was broken down into ten sub-categories as shown in Figure 3.5. The answers to these categories were given on a scale of 1 to 5. Answering 1 would indicate that sub-category was a strong barrier to the milestone not being met. Answering 5 indicated that the sub-category was a large enabler to achieving the current progress toward the milestone. The scale between 1 and 5 was continuous.

3.5.1 Survey Results

The results are given in terms of relative strength of barriers and enablers on a graphical ‘force field’ diagram. The size of the arrow is the indication of the strength of the force. The starting point of each arrow is the average score of everyone who answered the survey. For example, the tail of the arrow for “Availability of Funds” in the diagram below starts at about 2.0, the average score of all answers. If a certain question did not receive a unanimous answer a bar instead of an arrow is used. The length of the bar indicates the range of results, and the dividing line within the bar is the average score.

Three representative questions are shown below. The data for each question is presented, and then a short explanation of the answers follows.

Question #1:

Our target date for writing the *line* PO was 8/8. Why didn't this happen as planned?

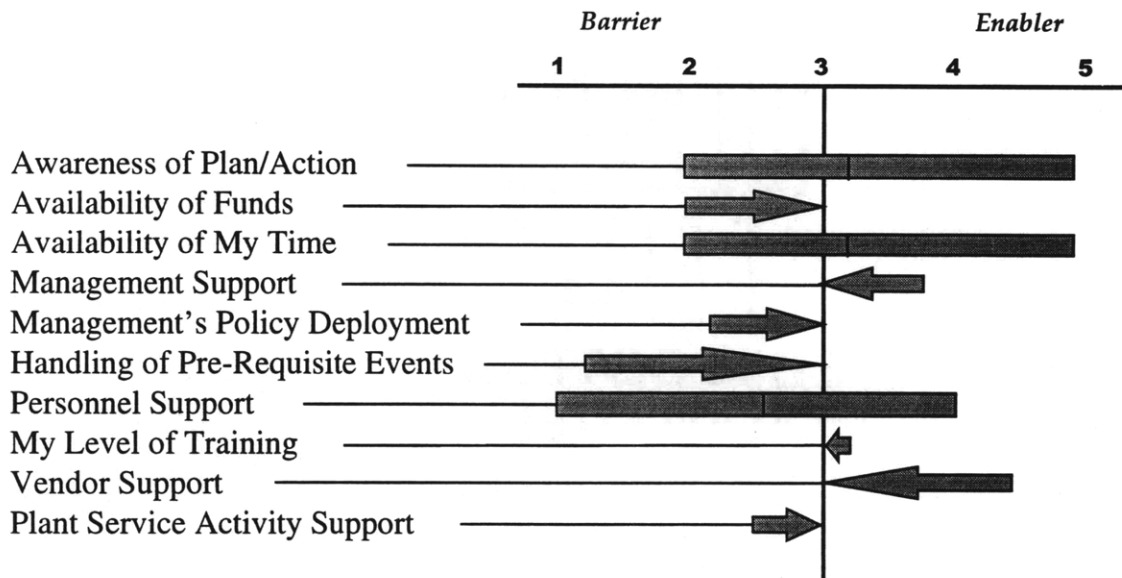


Figure 3.5. Results of writing the Line PO timing question.

The largest single effect in not meeting line PO timing according in the above data is the barrier created by a pre-requisite event. Some confusion as to what that event was, however, surfaced when each participant was probed further on the matter. Several answers indicated that the reason centered around the completion of the design – either with the decision making process concerning what direction to take, or in having enough engineering resources to complete the task in the planned time. Others pointed to funds not being immediately available as the reason for the delay.

The two clear enablers were the level of support from management and vendors. At this point in the project, management backing was strong, and vendors, hungry for the promise of related future business, were delivering quality work. Mixed results were logged for Awareness of Plan, Availability of Time, and Personnel Support. All of the barrier scores for these categories were logged by members of the engineering community

who felt somewhat overwhelmed at this time. This feeling often caused them to miss the morning launch meeting, thus possibly explaining why engineering consistently rated their Awareness of Plan lower than the rest of the launch team.

Question #2:

*Our target date for writing the **test equipment PO** was 8/8. Why didn't this happen as planned?*

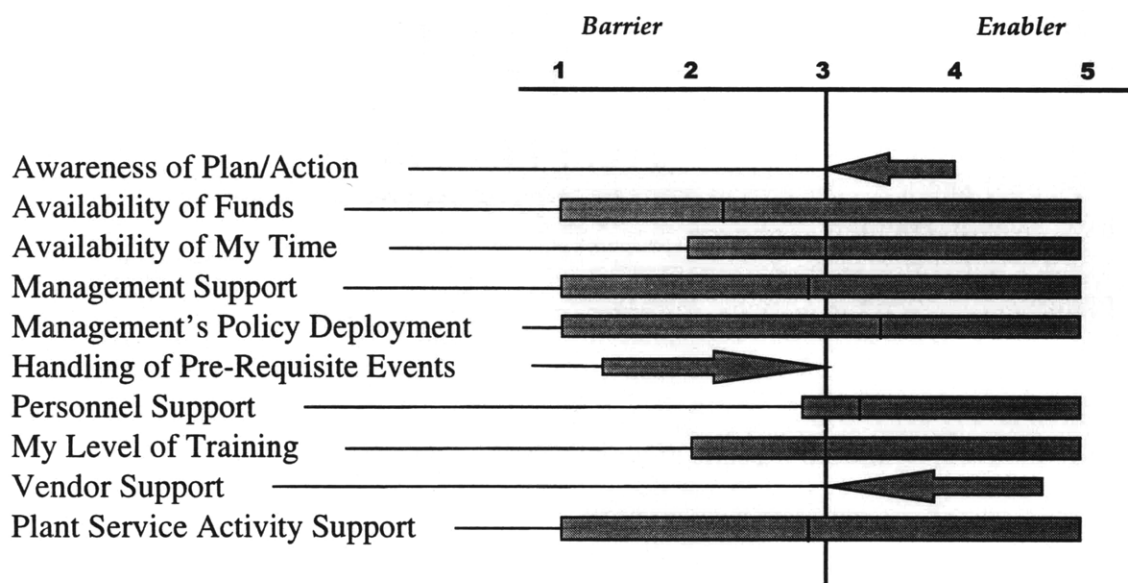


Figure 3.6. Final test equipment timing question results.

Once again the handling of pre-requisite events showed up as a strong barrier. Several different reasons were given for this question as well, however, in this case they all centered around the decision of what type of technology to use for testing. Because this was a new process in the industry, a new vendor had to be located and approved by the purchasing organization. There were also debates between the production and product engineering groups as to what technology was best for this application. All of these factors led to delays in the process. On a more positive note, the launch team was pleased with the support that the chosen vendor exhibited. Of interest in this question are the four responses that spread the full range from 1 to 5. The average of three of the answers,

shown by the vertical bar, fell on the barrier side. The average of the fourth answer fell on the enabler side. Closer examination of the interviewees show that all of the barrier responses came from Engineering. Engineering had the most difficult job of meeting deadlines at this time because vendors needed final approval of designs before they could start work making the equipment. This coupled with a short staff in Process Engineering created a reality that was different in that group from the rest of the launch team.

Question #3:

Do you feel the Niche Line will be launched before the end of the year?

Consensus answer: NO

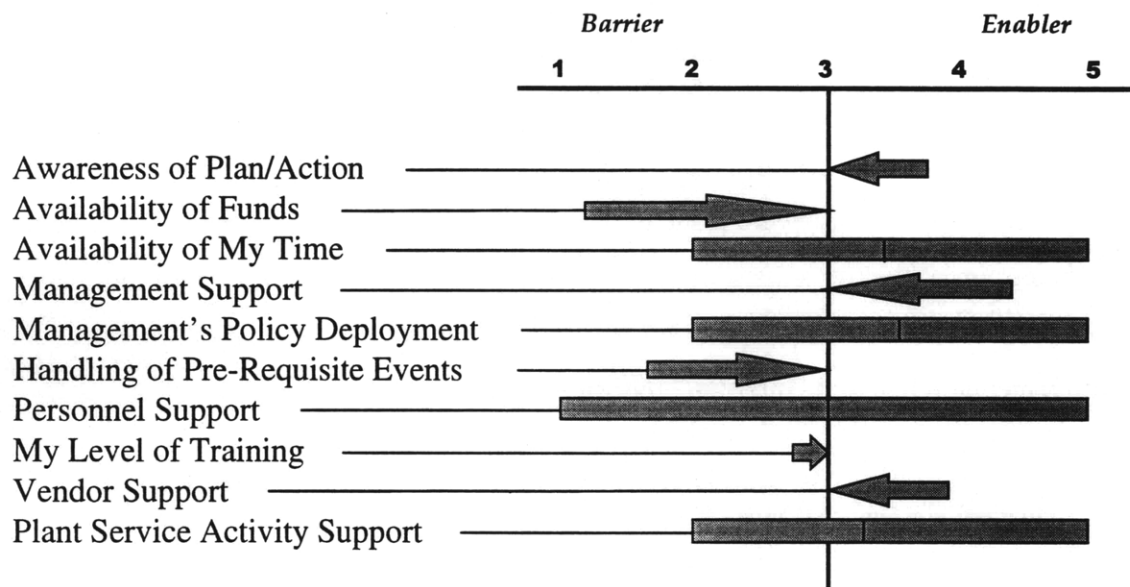


Figure 3.7. Final launch timing question results.

The reasons behind the dominant consensus answer of NO lie in the beginning of the project. By and large, the majority of the launch team members felt that events early in the project would lead to an overall late timing. These events dealt with not making decisions fast enough when ideas had not been solidified. For example, a project approval process that took four weeks instead of the one week allotted in the timing plan cascaded into several following tasks being late. Without project approval there were no funds to

spend, and without funding, POs could not be written. Without a PO, vendors were hesitant to start the design process on the product that they are supplying.

3.6 Overall Lessons Learned

There exist various lessons from this launch; some of which have specific meaning to the research site and some which have more general implications. The results will therefore be presented in two groups – those more specific to Silverton, and those that have more general implications for field practice. Of course, the reader may find that a Silverton specific conclusion also applies directly to his or her specific application.

3.6.1 Lessons having general implications for field practice:

- 1) In the launch of a new manufacturing system, team members (or a subset of) should be included in the decision making process prior to the release of all major engineering designs.**

At Silverton, many efforts were made to include some of the more experienced workers into the design of the immediate work surroundings. Some outside benefits of this effort were opportunities to have the production team input suggestions on overall process improvements, repair and teardown procedures, and rack out strategies.

- 2) While substantial attention is given to compressing technical development time during the design and launch of a new manufacturing system, a similar amount of attention is not normally made on the social side.**

Most of the effort in the Auto Industry in this regard is placed on the technical side of the business (product design and development, manufacturing system design and development). The social side is sometimes completely disregarded and (most often) implicitly disregarded. One example is the lack of importance placed on training. There is a fundamental lack in our ability to track and measure "social capital". This is best illustrated by the unanimous desire for training that the production workgroup expressed. When asked if they felt the role of training would be important in this launch, the responses were all similar to these:

"Training is very important. It gives me a better perspective of what is going on. I don't like theory, but when you have something you can put your hands on that works...I like that." (U.A.W. worker)

"Training is totally important – the production people have to have the knowledge of what they are doing. There are very few of us that have the knowledge. They were never required to figure calculations for quality, production rate, etc." (U.A.W. worker)

3) Management of the launch team's boundaries during the launch of a lean system is critical.

Proper boundary management can help to mitigate many of the rational and fabricated fears that exist when embarking on a radical change. The Silverton Plant used two tactics in boundary management that proved very successful: 1) email was used in this case to publish meeting notes to all stakeholders in the project, and 2) a large initial launch team was selected that was comprised of all disciplines (engineering, management, production team, industrial engineering, supervision, material handling). Each of these members was in turn able to act as a change agent in their own organization.

4) The success of the workgroup is interdependent with the design of the work system [11].

This goal in of itself should not be a constraint, but it is an outcome of properly designing the system around a set of good functional requirements. Some of these requirements include:

- Workers know exactly who their customer is
- Workers can identify problems elsewhere in the mfg. system
- Workers can easily assist other workers
- Every part must pass through every station
- There will be no repair loop
- Workers should not be assigned to a given machine
- Stations are designed with cleanliness in mind
- Walking distance should be minimized
- Work content should be balanced between workers

Observation that a lean system will revert to a "mass" system if old style management were to take over [1] is probably accurate for a vehicle assembly system where the lean

manufacturing design is not much different than the mass production one. However, in component manufacturing where a lean cell is designed much differently than a typical assembly line, old school management techniques will cause the system to fail completely – team work is essential to making the lean cell manufacturing system work.

A distinction must be made here between teamwork in the sense that the workgroup gathers once per week to try to make improvements, and a work system that is designed to enable teamwork while the job is being performed. This distinction is critical because ad-hoc problem solving is a large component of continuous improvement, and the more problem solving is enabled through on-the-job communication, the faster the production system will improve. If the system is designed, for example, so that when there is a problem it can be identified from anywhere, then teamwork will be the natural mode of work because the entire team can see and help to address the problem. On the other hand, if workers were isolated, as is sometimes the case in mass production systems, then teamwork will not be a natural outcome of the system design.

5) When launching a lean effort that is a subset of an overall operation that is not lean, an explicit effort must be made to buffer this operation from the remaining supply chain.

However, the operation cannot be "set on a pedestal" or its results will be discounted, disregarded, and undercut. Starting with assembly operations is a common theme in lean transformations. A question that must be addressed immediately is how to interface with an existing supply chain that is not lean. One solution is installing a temporary buffer. This buffer may take on different physical characteristics. In the case of Georgetown and NUMMI, they use nearby warehouses to store incoming components, and deliver them line side in a JIT fashion. On the lean line kitting was used. An external kitter removed the large quantity of in-house inventory off-site, and supplied Silverton back with JIT deliveries of kitted components. This process eliminated the space required for in-house storage, and it potentially will increase incoming component quality because the operation of loading the kits is another rough quality screen. Over time as the entire

Silverton operation becomes lean, and component parts are produced on a pull basis, the need for the kitting (along with its added cost and complexity) will be reduced.

3.6.2 Lessons having specific implications to Silverton:

1) When developing lean applications, manufacturing engineering plays a much more important role than in mass production.

The reason for this is that in lean manufacturing machines are designed for the demand rate of the customer rather than "as fast as possible". This creates a situation where, often, the vendor supplied solution is not appropriate. More specifically, vendors often are hesitant to do "custom" work where they don't see further demand for their generic solution. In developing lean manufacturing systems, Manufacturing Engineering must take a much more fundamental and dedicated role than they have in the past in defining functional requirements and design parameters. Because of the tight budget and lack of vendors who could integrate a lean system, much of the design and integration responsibility was placed on Silverton's Manufacturing Engineering department. This led to some situations that the group wasn't prepared for. For example, one of the build stations needed a sealant application machine. Current vendors of this type of product produced only expensive, high volume equipment. The launch team realized that their need of a simple, relatively slow machine were much different than what was commercially available, however, they didn't have the capabilities to design or build what they needed. This resulted in this piece of equipment coming in very late relative to the schedule.

2) The success of the workgroup is partially dependent on properly set expectations of workgroup autonomy. These expectations must be backed up with the correct level of resources so that the team can take full corrective action when necessary.

This became evident during a heated team meeting after a part of the new workgroup had started running the welder. The coordinator was tasked with having the team perform cleaning and preventative maintenance whenever the machine was down, however, he had few resources to do that. His comment to the supervisor was, "I can't clean a whole

machine with paper towels and a spray can!" The expected level of autonomy must be properly communicated, and in turn supported by local management.

It also must be acknowledged that lean does not mean autonomous. In some types of manufacturing where the workgroup has control over the entire manufacturing process, completely autonomous systems work well. In lean manufacturing, however, where standardized work is used as a basis for continuous improvement, and where a work team will have many interdependencies with up and downstream teams, completely autonomous operation does not work. There will inevitably be tensions about what the proper level of autonomy should be.

4. Project Management using the Enhanced Critical Path method

4.1 The Design and Launch Process

As described in the previous chapter, a very important aspect of this launch was the creation and use of a plan that contained both social and technical tasks in the same framework. From the start, the launch team decided to manage this process much differently than what had been done in the past. They realized that this would not simply be the launch of a new manufacturing system, but the introduction of a new manufacturing philosophy, and this would result in many technical and social hurdles to overcome.

A brainstorming process ensued to consider the options for planning and controlling such an undertaking, and what resulted was the decision to use a modified critical path methodology. This would enable everyone involved to have a simple visual representation of the project. Furthermore, unlike a Gantt chart, this method would provide a clear graphical representation of the project's complexities and interrelationships. The chart was organized such that social tasks, technical tasks, and tasks having both social and technical components were documented in the same space. This allowed the launch team to be cognizant of social and technical events simultaneously, and it also made possible, through the collection of task completion data, a post-launch analysis of successes and failures. Figure 4.1 is a fold-out of the Enhanced Critical Path (ECP) for this project.

A critical path chart is a graphical technique of explicitly representing both dependencies and timing of tasks. Each node on the example chart in Figure 4.2 is a task. Its position with respect to time is indicative of when completion is planned, and its relative position with other tasks represents task dependencies. The nodes in the critical path are labeled with the name of the task, and often with the planned task duration as well. Note also that this representation does not allow explicit coupling between tasks through the use of loops or feedback. The dependencies among all the tasks in a project, some of which may be arranged sequentially and some of which may be accomplished in parallel, allows the

critical path to be developed. The explicit definition of the critical path is the minimum possible completion time for the entire set of tasks in a project. Consider Figure 4.2. The critical path must either be A-C-D-E or A-B-D-E. Since the total time for A-B-D-E is longer, this represents the minimum amount of time in which the project can be completed. This is shown by the dark line in Figure 4.2. Identifying this path is important because a delay in any of the tasks falling on this line will cause a delay in the project. Likewise, the off-path tasks do not automatically create a project delay if they are late. These off-path tasks have slack build into them.

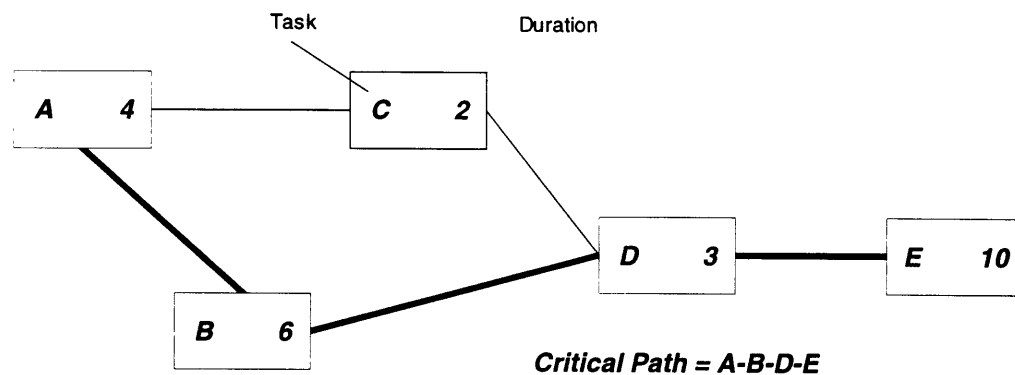


Figure 4.2. Critical path example.

The critical path chart used for the Silverton launch had several differences compared to a standard critical path as described above. First of all, it consisted of two separate paths; one for social tasks and one for technical tasks. Secondly, the critical path was not defined as the path of minimum total project time. This was primarily because the launch team wanted the events on the critical path to be those that contained large significance to the program. This significance was often, but not always, coupled with task timing. Furthermore, the critical path calculation was not rigorous because the time to complete many tasks, especially those on the social side, was not known with a high degree of confidence. Finally, because strict rules on timing were relaxed, coupling and feedback between tasks was allowed. This is illustrated in Figure 4.1 by the feedback loops visible between the individual assembly station design tasks. Therefore, the ECP was used not

only for project timing, but as a communication tool for the plant to better understand and take advantage of the interdependencies of technical and social tasks.

The first thing noticeable about the ECP in Figure 4.1 is that it splits in two after “Concept Generation”, and doesn’t come back together until “Launch”. This representation conveys the two distinct paths, social and technical, that the team had to follow. The social path is located above the technical one. Also notable are the weekly dates listed at the top of the chart and the corresponding weekly countdown at the bottom.

The organization of the individual tasks was done in accordance with the split critical path arrangement. The tasks that fit entirely into a social categorization were placed above the social path at the top of the chart. These included items such as team selection, teamwork training, and decisions on wage levels. The technical tasks were then placed below the technical path at the bottom of the page. Project finance approval, equipment engineering, and line installation all fell into this category.

The middle area of the ECP was used to bring the social and the technical aspects of this project together. The events placed in this area were ones that had strong social and technical interdependencies. Included here were items such as training in predictive maintenance, design and layout of the assembly stations, and development of a “practice field” assembly line.

4.2 Development of the ECP Chart

The creation of the ECP was done in much the same manner that any project timing tool would have been developed with a few exceptions. Those exceptions came later in the planning process when the team developed linkages between the social and technical paths. Chronologically, the launch team’s planning process went as follows:

1) Establishing hard dates

There was some flexibility here because the only firm date was the welder launch. A plan was made to run the new parts through the welder because that was a unique process, and

assemble the components down the main assembly line in Department 17 until the new lean line was running. This action would take the pressure off the launch, and it would allow the team to spend more time to design the line and train the workgroup.

2) Establishing goals

Because there was no hard launch date, management set a stretch objective of having the line installed and running before the Winter holiday. This objective was aggressive, but it emphasized the importance of the project. It also emphasized a goal of lean systems that they should be designed with simplicity in mind. The simpler the design, the faster it could be installed, the easier it would be to maintain, and the cheaper it would be to purchase.

3) Listing technical and social tasks that needed to be completed before launch.

Tasks that might be under the Social-Technical heading were included as well. This amounted to a list of everything that had to be done before the system was launched. Technical items included design and procurement tasks, social items included workgroup training and the setting of pay scales, and Social-Technical tasks included lean manufacturing training and the design of human interfaces on the assembly equipment.

4) Establishing lead times for each task.

Developing lead times for social tasks was somewhat ambiguous. “Social lead time” was not simply the time required to complete a formal training course. It included any tasks necessary to cognize a lesson. For example, if the team thought learning a particular concept required some formal classroom learning as well as on-the-job experience, then time to accomplish both of those things were included in the lead time. A more subtle point in social lead time is the concept of emotional readiness. After training and doing, there is further time required for mastery and full buy-in. This time was not included in lead time estimates, however, it was worth recognizing that training + experience does not necessarily equal a fully developed shared vision.

5) Comparing social and technical lists and determine if there were any sets of tasks

with strong linkages.

This step was where the power of showing both social and technical tasks in the same space was utilized. For example, training in quick changeovers, and error proofing had a direct linkage with work station design. These linkages were laid out as shown in Figure 4.3 before adding tasks to the ECP.

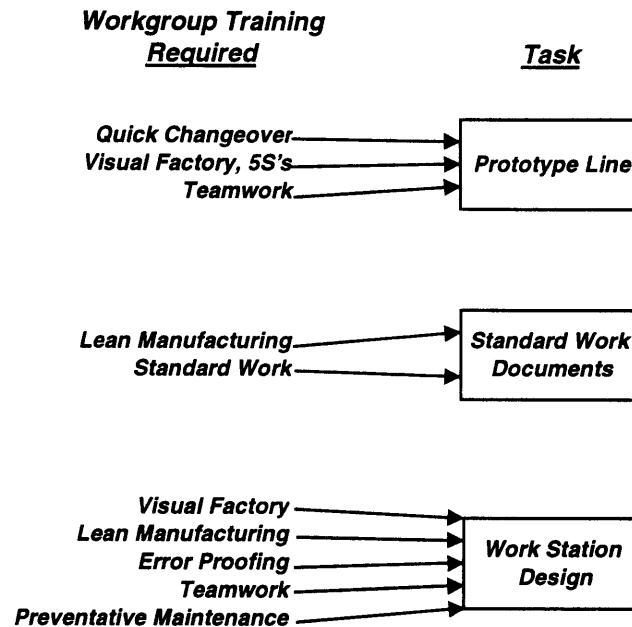


Figure 4.3. A few of the Social-Technical linkages in the Silverton launch.

- 6) *After linkages had been made, and these tasks placed in the S-T regime, the next and final step was to be creative and see if there was any way to leverage the social and technical sides off of each other.*

An example of that in this launch was the preparation of the prototype line and the prototype build cart. Both of these activities created opportunities in social and technical areas that would not have existed otherwise:

- A better understanding of the build process by the production team and the engineers.
- The creation of a team building opportunity for the entire launch team (hourly and salaried).
- A learning atmosphere was created within the production team. Workgroup members that were familiar with the component build process (those who had worked in the

repair area) were able to teach newer team members who had never assembled a complete product.

- Increased buy-in for the production team early in the process. Production team members were able to communicate openly about their ideas and concerns. Likewise process engineers were able to see clearly some of the details that often had detrimental impacts on production quality and throughput (ergonomics, safety, and process issues). This interaction affected the design of the equipment and the processes in several ways. For example, the production workgroup studied a proposed design for one work station where a cover plate was installed with ten bolts. Engineering had included a set of bolt starter guns much like the ones on the main assembly line. After looking this design over, the workgroup decided that the starter guns would be less flexible than simply using their hands. This saved several thousand dollars, and it added to the line's flexibility. Upon making this suggestion, one workgroup member said, "Starting ten bolts per part every five minutes is a lot different than doing it every seven seconds." Thus, the work team was showing an understanding of lean manufacturing and a willingness to improve the process even before the line was launched. Many other similar examples existed throughout the design process including suggestions for tool and part placement, tool design, and processing techniques that affected quality.

The launch team also had several realizations during the development and use of the ECP concerning the project:

- There was not enough time to get everyone in the workgroup through training. The training that was supplied by the plant was also missing some critical technical components. This led to formulating training exercises that would be supplied to the workgroup at a time that coincided with the introduction of new responsibilities. For example, after the welding equipment was brought in, a series of short lessons were developed around troubleshooting the equipment. Appendix II has some examples of these Single Point Lessons.

- The launch team decided to use the development of standardized work practices as a launching pad for teaching lean principles. This would have many ramifications including setting boundaries for work group autonomy, involving the work team immediately in the process, and teaching concepts such as quick changeovers and error proofing. It also helped in developing a production efficiency mindset within the work team.
- The team discovered that the test equipment planned for the line would be under a very tight time table. This realization initiated immediate talks with the supplier, and eventually it was decided to implement the new testing process at a later date, and to use existing testing technology in the interim.

4.3 Analysis of Project Timing Data

4.3.1 Using the ECP as a Feedback Tool

The launch team hung this chart in the “War Room”, and used it to judge performance on a bi-weekly basis during the morning launch team meeting. As time passed, and each task completion event was revealed, the team used a Red light, Yellow light, Green light approach to categorize how well they had met their timing targets. If the event was complete, a green sticker was placed next to the task. If the event was in process and near completion, a yellow sticker was hung, and likewise, if the event was far behind schedule a red sticker was used. Figure 4.4 is a sample of how the chart looked with these stickers in place. The stickers provided an excellent visual management tool for quickly discovering where the project was doing well, and where it needed more attention.

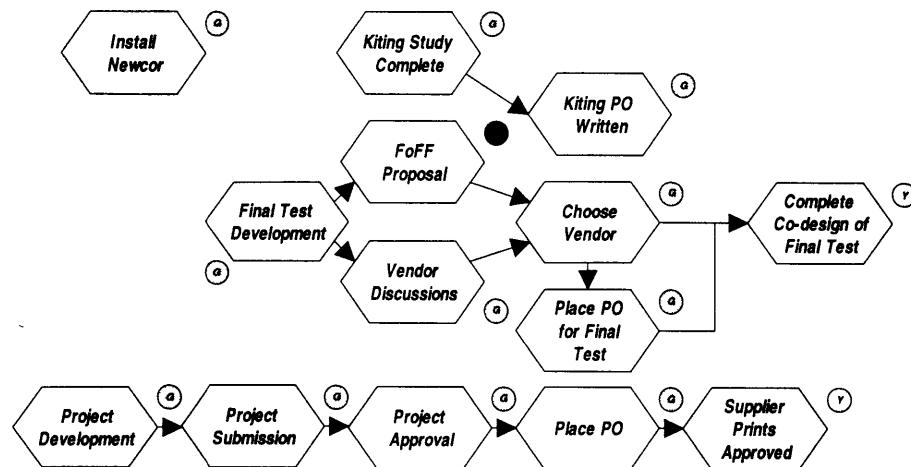


Figure 4.4. Use of ECP for project control.

As the stickers were hung, completion data was collected on each task. For example, the launch team planned that purchase orders would be placed for all work station hardware by October 6th. The records show that most of the purchase orders were placed by that time, but that task wasn't fully complete until October 23rd. The chart then showed a yellow sticker next to that task after October 6th, and a green sticker after the 23rd.

The full set of task completion data are illustrated graphically in Figure 4.5. This graph shows the cumulative percentage of task completion on the Y-axis, and time on the X-axis. Time is split up discretely into intervals of one month, starting August 15th and finishing December 15th.

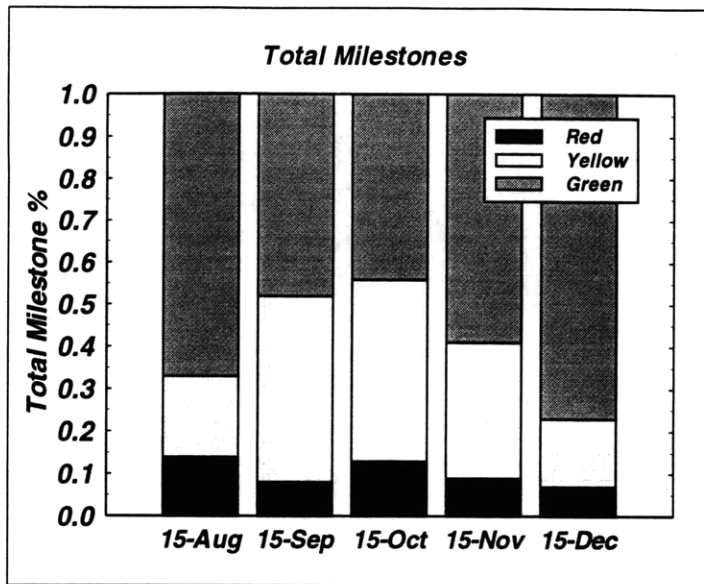


Figure 4.5. Schedule performance based on total milestone input. (red bottom, yellow middle, green top)

4.3.2 Splitting Task Completion Data into Components

The charts in Figure 4.6 are laid out identically to that of Figure 4.5 except that those data are broken out into Technical, Social, and Social-Technical components.

Superpositioning the data from Figure 4.6 results in the chart in Figure 4.5. Of particular interest is the observation that none of the component data sets look much like each other, nor do they represent the Total data set in any significant manner.

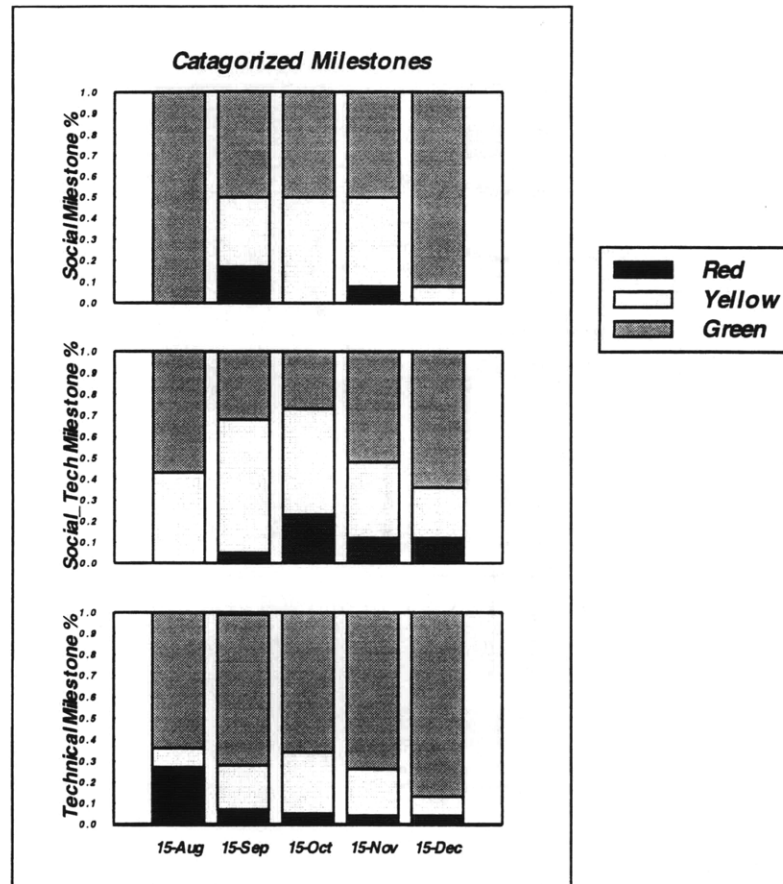


Figure 4.6. Technical, Social, and Social-Technical components of overall schedule performance (red bottom, yellow middle, green top).

4.3.3 Analyzing Task Completion Data

Figures 4.5 and 4.6 illustrates several key points:

- *The project was not completed on the planned time scale.* Launch was planned prior to the final December 15th date shown, and several tasks were incomplete at that time. The plan shown in Figure 4.1 was conceived in early July, and by December the project was approximately eight weeks behind schedule. Most of this difference can be attributed to planning being aggressive to the point of wanting to install machinery before the Winter shutdown in mid-December. Because of several plant resource constraints, installation of the line was subsequently rescheduled for the shutdown period.

- *On the Social-Technical boundary there still exists a lack of expertise and focus.* Percentage of uncompleted tasks in this category far outweigh the other two. One reason for this is that many of the tasks in this area were unconventional and had unproven effectiveness to the plant. For example, building a “practice field” area where different assembly techniques could be experimented with, and where assembly training could begin was considered somewhat of an experiment. Another strong factor was that for many of these tasks to be planned properly, a large block of uninterrupted time needed to be scheduled. With most production employees working every Saturday to support current production, this became difficult.
- *Socially, there were a few areas such as setting wage levels that fell behind schedule.* However, in December there didn’t exist anything that could be labeled a show stopper. This can be attributed to the advent of the Organizational Development⁵ department at Silverton. Its existence created a heightened awareness concerning social issues. The Silverton plant contained ample resources for training, managing change, and developing workgroups.
- *Technically, the project was clearly under control at this point in time.* The relatively smooth linear trends suggest that the plant had plenty of experience in dealing with technical projects. There is also a clearly visible “end effect” as the Winter shutdown approached, and the installation schedule could not be allowed to slip.

⁵ The OD department was created to aid in the transition to more effective work systems. It consisted of both union and management representatives who spent about half of their time managing current crises and the other half aiding various production departments with change initiatives.

There are also several important factors that the data failed to capture:

- System launch effects. The data fails to represent any difficulties that resulted after the system was tested for the first time because the data time line does not extend past the point of system integration and tryout. Several unforeseen technical problems arose during the initial running of the system because Silverton was acting as the system integrator on this project, and because the system construction made it impossible to conduct any meaningful tryouts prior to installation. These setbacks, caused by a vendor miscalculation, were not represented in the data set presented above.
- The launch team failed to foresee the entire scope of tasks a priori that needed to be completed. This created a situation where not enough detail was included on the technical tasks. Overall completion data was unaffected, however, this may have impacted the shape of the month-by-month data shown in Figure 4.6.
- Unforeseen work was not captured. For example, preparing the installation area turned out to be a much more complex job than what was anticipated because of the discovery that the concrete floor needed to be removed and re-poured. These events pushed out some of the technical tasks later in the launch process, however, the data set is not able to capture the reasons why.
- These data failed to capture the ‘fuzziness’ of the social tasks. For example, completion of training does not necessarily correlate with someone having working knowledge of the material. Some assuredness exists in this, however, because the launch team attempted to take advantage of training as soon as possible by engaging the workgroup in activities that reinforced classroom work. The development of standard work documents soon after training was completed is an example of this.

Challenges to validity aside, these data illustrate with high confidence the initial hypothesis that management of the Social-Technical tasks that bridge well defined social

and technical areas need the most work. This is further supported by the realization that there are specific departmental structures within Silverton to address social issues (Organizational Development) and technical issues (Engineering), but up until this launch, with the introduction of a cross functional launch team, there has never existed an explicit mechanism to deal with Social-Technical issues. Furthermore, this may not have been a critical issue for mass production systems where human involvement in the manufacturing process was much less important.

4.3.4 Spillover Effects

Another important factor that the task completion data does not completely capture is the coupling of up and downstream events. Was a task late because of poor execution, or did it get delayed by a coupled upstream task? Fortunately, some answers can be found in the interview data presented in Section 3.5.1. For example, these data showed that a very early task, receiving project approval, caused many downstream ripple effects when this was not completed on schedule. One result was that the PO for the line was not written on time. This is captured in Question #1 results by barriers shown on both *Availability of Funds* and the *Handling of Prerequisite Events* responses. Some recovery actually occurred later in the launch because the vendor was able to put extra effort into working faster; an effect also captured in the Question #1 interview data by the enabling response on *Vendor Support*.

4.4 Improvement Opportunities

In early January, the launch team had a chance to gather and discuss the ramifications of these data. Several improvement suggestions and comments surfaced:

- The quick changeover, error proofing, and predictive maintenance training should be moved sooner and in smaller sized modules to prepare for the workstation design tasks. This would allow the production team to get a better grounding in some of the basics that were necessary in providing good input into the design process. This was a recognized shortfall during the planning process, however, development of Single

Point Lessons for these areas was postponed. The workgroups, then, had to rely on more formal classes for their only form of training.

- All other training should not be addressed so aggressively during the next launch. There existed the feeling that training was being completed just for the sake of getting it done. Shorter training sessions, given at appropriate time would result in more learning. For example, a simple lesson in machine cleaning and inspection could be given by the Advisor or Superintendent during a time when regular preventative maintenance was scheduled. This timely lesson would be codified much better than if it were given in a classroom setting, and less total time would be spent on training.
- Daily events associated with running the business were definitely a factor in meeting deadlines. Daily production numbers always had to take precedence, and that sometimes detrimentally affected the launch execution. In times when the auto business is booming, these effects are difficult to avoid.

4.5 Reflections on Use of the Enhanced ECP

- The technique presented an excellent way to see all aspects of the project at once.
- It was a good reminder for everyone involved in the project that social and technical components have strong, mutual interactions.
- The tool proved valuable for leveraging the social and technical sides of the business off of each other in ways that typically are not done. Examples of this include the establishment of the prototype line practice field, and using the production team to help design workstations and layout in the part kitting containers.
- Even if the Social-Technical tasks were completed in a ragged fashion in this launch, the fact that this work was explicitly addressed went a long way in building project ownership and team skills. Few of these ideas would have even been tried in past launches.

- Other tools than the ECP, like the Gantt chart or standard critical path, may work better for situations where exact project control and timing is critical. However, the ECP works very well for processes where less defined, but very important, coupling between tasks exist.

5. A Change Model for Lean Manufacturing

5.1 Why is Change so Difficult in Large Companies?

Large companies have been known to make successful and drastic change. The stories of Chrysler and NUMMI are well known. In both of these cases dire need for change was the overriding driver. In Chrysler's case, if they had been remiss in taking drastic measures of changing their business processes, they would be gone from the marketplace. In NUMMI's case, the old Fremont plant was among the worst at General Motors. It took nearly a two year shut down and a complete fresh start for that plant to make its dramatic lean transformation.

The stories of greenfield successes are also well known. Saturn is a classic example. Launched in 1986 thousands of miles from the next nearest GM plant, it was a grand experiment in doing business in very different ways – from product design to manufacturing, union contracts and even the customer's buying experience. In large, Saturn has been considered successful in its different approach to the automotive business.

The vast majority of industrial transformations, however, fall into neither camp; they do not emanate out of a major crisis, nor do they get a chance to erase history and start with a clean slate. Most corporations that want to move toward lean manufacturing are doing moderate to well when they commence their change initiative. This poses a unique challenge to anyone that starts a lean transformation. In the case of the Silverton Plant, there was a general feeling that things could be better, but there was no crisis atmosphere, nor was there any opportunity to stop everything and start over. In that respect, the Silverton experience exhibited many of the classic resistances to change:

1. It was instituted where there was only moderately perceived need by some of the stakeholders.

2. It was a systemic change cutting across many functions and power structures. It, therefore, required many people to change simultaneously. Tension and confusion can be created in this situation if the change process is not managed well.
3. The benefits were not all immediately noticeable or quantifiable. Without strong leadership, this could lead to a reversion back to old methods.
4. The dilemma of managing complex change while maintaining enough stability to continue to fulfill current customer commitments was very difficult.
5. Finally, the change may not have been viewed as being beneficial for everyone involved. Real or perceived fears can have disastrous effects on change initiatives if left unchallenged.

The change to lean manufacturing also had a few specific features; in the Silverton case the following were found to be true. Many of these points may be generally applicable to other manufacturing change initiatives as well.

1. The metrics are much different. Rather than relying only on equipment and labor efficiency to gauge performance, lean metrics are much more customer focused measuring quality, responsiveness, and *total* costs.
2. The distribution of power must change. The production work force will gain power as their responsibility for day-to-day operations increases. This is often a point of contention with production supervision as they are required to submit some of their power to the manufacturing workgroup.
3. This change in metrics and work practices must be backed up by physical manufacturing systems that can support these business goals. This requires a large shift in technology emphasis, which can be difficult for the engineering and equipment supplier community to gain a complete understanding of. Lack of technical understanding can result in poor alignment and sub-optimal work system design.

While many of the requirements for change and the techniques to effect change are relatively constant across any initiative, each of the above differences that lean

manufacturing has with respect to mass production requires specific attention during a lean transformation. The heart of the difference lies in the coupling of simultaneous social and technical initiatives that lean manufacturing requires. For example, a change in work practices, a social change predominantly because of the introduction of workgroups, interacts very closely with the design of a work system that allows teams of people to work together effectively. This coupling of social and technical initiatives suggests that the change process itself should explicitly and simultaneously address both areas. However, current literature on change has fallen short in addressing the full extent of this coupling necessary during a lean transition.

5.2 An Overview of Organizational Change Models

Managing change has become an increasing concern for all companies as competitive forces of global competition continue to grow. As the need for change has increased, so has the body of literature that documents successful and not-so successful practices. Some of the theory presented here comes from the technical literature. Its concentration is mainly focused on integration and acceptance of new technology. The other main body of change literature comes out of the social sciences, and much of it focuses on the dynamics of transforming corporate culture. While both sets of literature address various viewpoints of change, very little of it treats the social and technical perspectives as a system. This review will cover relevant theory pertinent to managing change that has social and technical implications, and it will attempt to fill in the gaps and point out shortfalls from the perspective of the Silverton launch case.

Traditional methods of thinking about organizational change have centered around the work of Kurt Lewin. His three stage approach of “unfreezing”, “changing”, and “re-freezing” [13] held a dominant position in the literature for several decades. According to this approach, an organization prepares for change, implements change, and then strives to regain stability soon thereafter. His approach may have been appropriate for organizations operating in times of relative stability, and where the technology being implemented was relatively inflexible to future changes. However, today’s competitive

environment requires that new technologies are appropriately flexible and customizable; hence the emphasis in lean manufacturing on continuous improvement. Therefore, Lewin's model for change, especially with its emphasis on stability in the final stage, is not completely appropriate for a lean manufacturing transition.

Some researchers have tried to compensate for the Lewin model shortcoming by proposing more of an improvisational change model [14]. These models, based mainly on the introduction of information technology into an organization, are very open ended. They frame change as beginning with an objective rather than a plan, and proceeding toward the objective in an ad-hoc fashion, responding to conditions as they arise. These models assume that technology and organizations can be quickly and cost effectively transformed with complete flexibility. Unfortunately, changing the hardware that a manufacturing system is based on is time consuming and costly, therefore, planning rather than improvising must become the dominant mode of change in lean manufacturing. This is not to say that being open ended is unimportant. Continuous improvement requires that systems are open ended to a certain extent, but that is bounded when dealing with capital intensive manufacturing equipment.

Other models have recognized the importance of alignment within an organization for achieving the goal of the change effort. Beckhard and Harris [10], propose an exercise in present and future state mapping as a method of creating a clearer picture of what will be required during transition. Present state mapping is an enlightening means of detailing exactly how the current system operates, and future state mapping follows on to have the group agree on where the organization should be headed. This effort focuses on bringing stakeholders together to develop a clear picture of the efforts necessary to create the desired change. Their case studies show how this effort brings alignment into the organization, and how it helps to build a shared vision of the future.

The Beckhard-Harris model also addresses the need for dedicated resources during transition. They accomplish this through several case examples of transition failures that result from a lack of focus on the transition state. The authors point out that the transition

state is very different from either the past or future states because 1) normal business must go on as well as change activities, 2) extra clout to mobilize resources and cut thorough red tape is usually necessary, and 3) a specific transition action plan must be developed and used to control the progress of change. Each of these points applies directly to a lean manufacturing transition.

One drawback of the approach is that the final state is treated as a static goal, and this could lead to the pronounced affect of 'collapsing over the finish line'. This is especially true when making a transition to lean manufacturing where the 'final state' must be considered the starting point for further improvements. Their model also does not address any specific social and technical interdependencies, other than creating a shared vision, even though many of the examples used are change driven by technology.

Other approaches have concentrated on the importance of leadership and top-down change [15]. According to these models, leadership can be divided into two categories; initiating sponsorship and sustaining sponsorship. Initiating sponsors of change are in a position with enough authority to mandate that change must take place, and furthermore are able to supply the resources to support the change. Sustaining sponsors then are tasked with the actual implementation process. The authors argue that initiating sponsorship and sustaining sponsorship are unique roles, so that the directive and the action can come from two different sources. This provides political cover for the sustaining sponsor who must place him or herself in a potentially vulnerable position.

Unlike the more incremental change approaches of Lewin and Beckhard, many of the more top-down approaches suggest more decisive, rapid, and fundamental change [16] These models recognized slower, more incremental change that involved all stakeholders had limited value in settings where change involved multiple interests or major shifts in the power structure.

One advantage of these models is that the role of leadership is addressed, and they address how fragile the process is during the transition phase. They implicitly discover

what Beckhard and Harris did about dedicating resources to the transition phase, however they go a step further and illustrate the danger of removing a sustaining sponsor during this phase. One drawback surrounding these models is that they treat the final state as static, and the more aggressive approaches [17] which recognize that the “market for change” was getting impatient with the pace of change, fall short in their understanding of what role the workforce should play in a successful lean organization. Workers in fear of being tossed aside in order to “maximize shareholder value” will have few incentives to put extra effort into continually improving their work system.

More recent schools of thought attempt to bring together the social and technical in a more coherent picture. For example, Chew et al. [18] propose that “The introduction of technology should be considered less an investment issue or technical issue and more a question of research design.” This research can take the form of simulation, prototyping, or on-line learning about technology, *and* organizational issues. Chew also recognizes other benefits in prototyping and modeling the final system – like getting input from the whole team, and using these activities to build teamwork and buy-in. The ideas presented address the social-technical interdependencies but only as a consequence of trying to mitigate potential errors. Leveraging social and technical aspects of an initiative is not discussed.

Another useful framework presented in Chew’s work is the Murphy’s Curve shown in Figure 5.1. Often the adjustment costs of a project are under predicted in the planning phase. The phrase ‘ramp up’ even indicates that a change initiative will not have any downturn at all, but that it will simply take some time to achieve the expected performance levels. Chew’s data indicates that “statistically significant negative effects often persist for more than a year after the introduction of new equipment”, and he makes a clear connection between this downturn and unknown factors that arise because of a lack of knowledge concerning both new equipment and the current processes. The suggestions presented in this work all focus on implementation efforts, however, they fail to address the impact of system design on start-up issues. System design is taken as a

starting point here rather than an opportunity to reduce adjustment costs through better design efforts.

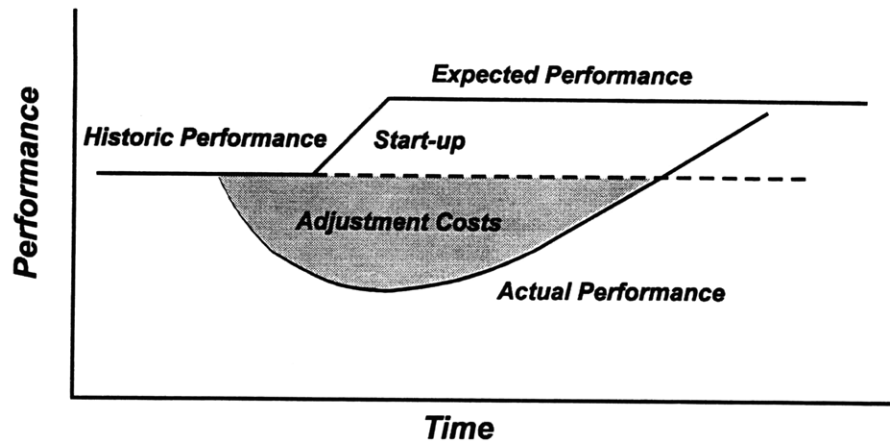


Figure 5.1. “Murphy’s Curve. Adapted from Chew et al. [18].

Finally, there is a genre of work that concentrates on change in unionized environments. Turner et al. [19] present a change model that is tailored to manufacturing facilities moving toward more participation and democracy in the workplace. It addresses this issue through a chronologically organized set of actions that they recommend as a recipe for change. This recipe is (in order): Initiation, Joint Design, Implementation, Continuous Improvement, and Evaluation and Planning for Evolution. Their change model has many strong points, especially concerning their recognition that the change process does not end with implementation. They take this concept to the point of dedicating two of their five steps to post-implementation activities. They also illustrate several cross-cutting features of successful change that recur throughout every step in their change model. These include leadership, partnership, communication, training and positive incentives. They point out that strong, action oriented leadership is what underpins the process, and without it (both on the management and union sides) the change initiative will have little credibility.

What is lacking, as is with most of the other change models, is any explicit recognition of how technology affects change. Many union workplace transitions do not address

technology directly because the main goals are increasing the autonomy of unionized labor, and establishing better relationships between the union and management. This is fine for that specific set of circumstances, however, many increases in workforce autonomy are coupled with a move toward lean manufacturing. This requires a change in manufacturing technology, and therefore, this model falls short in that dimension

Another approach to change in union or non-union shop settings is negotiated change [20]. According to Walton et al., in any negotiated change there can be 1) forcing, 2) fostering, or 3) escape. In many cases there may be combinations of the above. For example, in a lean transition there will be a degree of forcing (we *will* be lean, we *will* reduce inventories), and there will also be a degree of fostering (brainstorming, present and future state mapping). Escape is considered the failure mode when neither side can agree on how or if change should proceed. This lens for looking at change is especially insightful for lean manufacturing because the strong social and technical coupling can cause numerous decision points where either forcing or fostering may be chosen, and the success of the transition can ride on choosing the right path.

Collectively, all of these studies clearly illustrate the importance of the change process on the overall success of any change initiative. As pointed out in the criticisms above, however, none of the models are completely appropriate for planning and executing a transition from mass production to lean manufacturing. This transformation is difficult (but not unique) in that it requires large technical and social change to be fully implemented, and unlike a change that involves the introduction of enterprise management software or a change in the corporate hierarchy, the physical design of a manufacturing system is not completely open ended to change. Therefore, planning, not improvisation, must be the dominant action mode. The above models also leave out several important factors including:

- The importance of technical success. Poor system designs cause frustration and team breakdown.

“...for with poor or non-coherent design, no amount of patching or management effort can make the system work well. Operating skills are vital, of course, but alone they will not carry the day. The greatest skipper cannot win the race with a badly designed vessel.” (William Skinner) [21]

- The strength of the linkage between the social and technical sides of a change initiative. Techniques for leveraging these linkages is one of the main focuses of this section. Because traditional models tend to focus on the tangible they make certain assumptions about time and implementation. Traditional planning models assume that there will be predictable variances in holding to schedule. The findings of the study in Chapter 4 show that indeed, the variance on technical (tangible) tasks were predictable, but that variation on the social and social-technical sides can be large. A complete change model will address that issue, and it will attempt to reduce the variability associated with social and social-technical tasks.
- The risk associated with such a transition without sustained and capable leadership. Making a mass to lean transition requires the leadership of a unique individual – someone who understands fully the social and technical philosophy of lean manufacturing.

What is needed then, is a more comprehensive change model that is designed especially for a social-technical transformation. One possibility for such a model is presented below.

5.3 Mass Production to Lean Manufacturing Change

It is impossible to create a single guide that everyone can follow for every circumstance, however, it is worth extracting specific examples from the Silverton case and presenting those lessons learned. These lessons will not be the definitive answer to the question of how to transform a brownfield operation from mass production to lean manufacturing, however, many of the experiences of this event are surely to be replicated in other similar initiatives. In that spirit, if this change model is to be useful, it will be because the reader augments his or her own knowledge onto these experiences.

One of the great challenges with making a mass production to lean manufacturing transition is that the entire business system is designed around mass production: physical systems (manufacturing and material handling), management systems, accounting systems, and human resource systems. In other words, many of the core competencies of a manufacturing operation suddenly get in the way of the transformation. In Dorothy Leonard-Barton's words, "core competencies can become core rigidities." [22] This can have a severe damping effect on the change process.

These core rigidities are caused chiefly by established mental models [23] that give incomplete attention to social-technical interdependencies of change. The goal of this change model is to give the experienced manager, with established mental models of their manufacturing environment, some tools in giving consideration to issues that they otherwise might not have.

A successful model for transition to lean manufacturing should have the following seven characteristics:

1. There should be some method of identifying a launch team, key leadership, and the production team. These teams must cut across all of the important power structures in the organization.
2. A shared vision should be established among all stakeholders.
3. A method of evaluating the performance of the change effort should be established and used for getting back on track if necessary.
4. A means of keeping stability in the current system should be designed. Satisfying current production demands needs to be kept as a priority.
5. There should be a means of simultaneously addressing social and technical issues and their interdependencies. These interdependencies should be leveraged toward the success of the change effort.

6. A system design process should be instated that insures that the physical manufacturing system meet the lean design guidelines (Chapter 2).
7. There should be safeguards against social or technical surprises that will arise during the launch process. These surprises can be turned into learning opportunities for finding better ways of accomplishing tasks.

5.3.1 Mass to Lean Change Model

There are two basic types of change that take place with lean manufacturing – radical change and incremental change. When making a mass production to lean manufacturing transition, radical change is necessary. After this initial transition, an incremental path should be followed as the system is continually ‘kaizenized’ through a series of planned improvement activities. A model for radical change is presented here.

The four point model presented below is a rough road map for implementing a change to lean manufacturing. Many of the lessons that went into this model were based on the experience illustrated in the Silverton case study. This experience was collective in that many people were involved in the learning process, and the experience was guided by many of the parties involved that had experience with dozens of other launches.

Therefore, this change model represents lessons learned while the case study research was being conducted as well as from the combined experience of many other change histories. Specific lessons from the Silverton case will be highlighted as side bars. These will hopefully add anecdotal evidence for the points at hand.

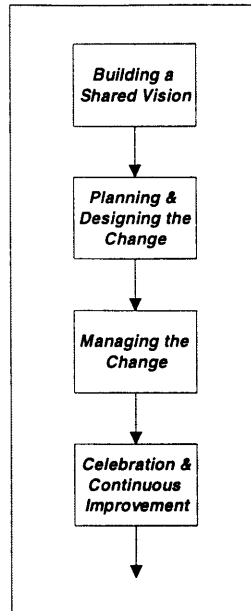


Figure 5.2. Model for lean transition.

The major subsections of the model in Figure 5.2 are straightforward. It is the details under each heading, however, that make the model unique. Embedded at various points in each subsection are the seven characteristics mentioned above. These characteristics drive the change from both the social and technical perspectives, and they provide methods to leverage one side off of the other for a more robust final state. A good model for change is required, as outlined in Chapter 1, to launch quickly, improve the work system design, and to enhance the improbability of the final state through better technical skills and communication.

To ready an organization for the radical change necessary to accomplish a transition to lean, it is necessary to attempt to align everyone toward a common goal. Lean manufacturing, after all, is rooted in the ability to improve work processes, and improvement means involvement and change by everyone. Change, at this level, takes place one person at a time. Anyone not included in the process will not only be left behind, but they will weaken the overall system in the long run. An attempt must be made to align the organization along a single pathway to change.

Building a Shared Vision

The first step in building alignment is defining the need for change. There are several methods for doing this, and all of them are applicable depending on where in the roll-out phase the organization is, and what level within the organization is being addressed. For managers who set policy, it is appropriate to think in ideal terms – minimizing all waste [24]. This process provides inspiration and direction along the path to lean, and it frames the problem so that the areas in most need are highlighted and can be attacked first. Also necessary, as Beckhard points out, is to map the present state so that a baseline can be established and problem areas can be easily identified. At a lower level of the organization, it is just as important to insure that production workers are a part of the transition. Building a shared vision among these employees also requires thinking about current and future states, but it also requires some further training in areas such as business basics and manufacturing measurables. This training serves both to educate and to build a common language around the change process. Since this part of the organization is most affected during a lean transition, lack of any shared vision of the future state can lead to breakdown and revolt against the process itself.

Silverton Sidebar:

The production team and direct supervision spent 104 hours in training during the transition process. The topics covered everything from UAW history to the principles of lean manufacturing. Additionally, the team spent time in team building sessions, and they attended daily launch meetings – partly in an effort to engage them and build their vision of the future. The combination of classroom learning and implementation exercise during the daily meetings was very beneficial for the few production team members that were able to take part. Simple logistics limited the number of participants in such meetings, but by choosing the most senior production team members to attend, the launch team was able to create a strong communication conduit with the remainder of the team.

Other techniques that should be used for building a shared vision include:

- *Proper team selection (launch team selection, work team selection)*

There are actually two teams that need to be chosen in the course of a lean transition. The first team is the launch (or transition) team. Many change efforts based on new manufacturing technology are directed by engineering and do not utilize a team structure for the transition phase. Instead, systems are designed and implemented with little buy-in from the production floor. In a lean transition, the effort cuts through many levels of the organization, therefore a launch team consisting of key stakeholders is needed to orchestrate the effort across the organization. This team is tasked with actual implementation of the change including everything from gaining financing to engineering, training, and actually launching the system. Another responsibility of the launch team is choosing who will run the operation after it is complete. Much of the time there is no choice – the people who ran the old operation will run the new one. Some times, however, a choice must be made about who will run the new operation. This decision can be critical; especially when a large plant is just starting a lean transformation. In these cases, there is some debate over which way to proceed – hand picking production team members from among the best employees, or using the employee base that currently exists in the transition area. The question is whether a plant should choose the team to ensure success of the initial implementation, or possibly take a more risky route and implement with workers that are less talented and energetic to start out. The latter route, if successful, can have the consequence of making the rest of the plant think, “If they can do it then so can we.” Finally, a strong launch manager must be chosen. His or her function is to provide leadership for the launch team.

Silverton Sidebar:

The Silverton plant had a Best in Class (BIC) policy for staffing jobs if a new product was being introduced. In this case, the product was not new, only the manufacturing system was, therefore the production team had to be chosen from a surveyed pool consisting of employees from Department 17. This created a situation where some very high performing people came to the new work system, however, some low performers came as well. Survey results of the production team's higher seniority members indicated that on average, they felt that about 20% of the team could be considered leadership material, about 60% were trainable, but the remaining 20% were questionable in their ability to perform the job. This indicates some concern from experienced production workers over some of their team members' abilities and dedication. However, if this team is viewed as being successful by the rest of the plant without resorting to BIC hiring practices, then other department's confidence in their chance of success may increase.

- ***Benchmarking***

Benchmarking has long been known as a way to learn best practices in a given industry. However, probably more important, is benchmarking's ability to create a desire for change simultaneously among many stakeholders. Choosing the right set of people to include on a benchmarking trip is a key to creating buy-in. The team should be properly represented from management, engineering, finance, and the production floor. The facilities to be benchmarked should be chosen such that they represent key elements of what the future state should look like.

- ***Team building offsites***

As intimidating as this may seem to the most hardened plant employee, team building sessions work well in creating camaraderie and in goal setting. These sessions also serve to get the team away from the work environment, and allow people to build relationships without the stress of a production schedule. The agenda at these sessions should cover the development of the vision for change, and it should help to set an agenda, so upon returning to the plant the team is ready to take action.

- *Starting in the right place*

If the initial lean transition area is a department that is buried in the plant's value chain, then the goals and the impact of the change will be difficult to conceptualize for the launch team. Instead, an initial application area should be one that is near to the plant's final customer. This clarifies the goals of the operation (operating at customer's takt time, clear quality implications), and it adds visibility that would be missing if the initiative were obscured among other operations. It also creates a kernel from which the rest of the plant can become lean. A logical next step would be to transform the department directly preceding the initial application area to create a series of linked lean departments [25] that produce goods in lock-step with each other. An illustration of this linkage is shown in Figure 5.3.

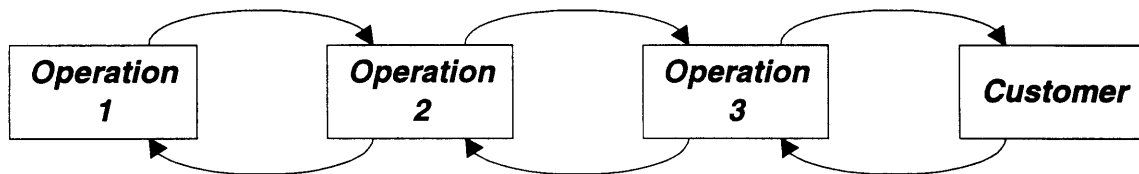


Figure 5.3. Linked lean operations. A lean transition should start with Operation 3 since that is closest to the end customer.

The importance of the alignment phase of the change process cannot be understated, however, many American companies pass quickly over this exercise to get to the 'real work'. What must be considered in a change as dramatic as moving to lean manufacturing is the entire implementation time. The diagram below illustrates the differences between typical Japanese and American implementation processes. Two things are immediately noticeable: 1) the Japanese finish with implementation quicker than American firms, and 2) the amount of time they spend discussing the change is much longer. What underlies this behavior is that American firms tend to start the whole process with a mandate for change and proceed directly to the implementation stage. They ultimately take longer to implement change because no clear vision was set. Different factions work toward their interpretations of what the outcome should be, and in the end this results in mistakes and re-work because none of the pieces fit together cleanly. The Japanese, who spend time

developing a clear vision, race through the implementation process because everyone is working together. Taking the time to set a clear vision will ultimately reduce overall implementation time.

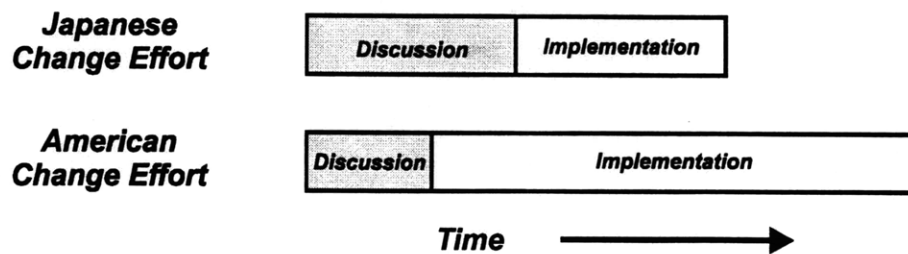


Figure 5.4. Comparison of American and Japanese change efforts⁶.

Planning and Designing the Change

The notion that a change initiative can be completely planned, and that the end result and the pathway to that result will be both predictable is a falsehood. Management, however, often sees change in just that way [18]. From a technical perspective, it is often hard to predict where a problem from imperfectly understood equipment will arise. From a social perspective, it is also hard to predict exactly where training is needed, what skills are missing, and where resistance to change will come from. Thus, the planning process itself should directly address issues of technical or social variability and attempt to minimize any surprises, and it should also be flexible enough to adapt to unplanned events. The realities of a lean transition are, however, that aggressive deadlines are set, and meeting these deadlines is important to the financial success of large scale projects.

The project planning completion data in Section 4.3 shows that the variance to schedule of the technical tasks was much less than that of either the social or social-technical tasks just prior to launch. This indicates two things: 1) that the process for completing the technical tasks was executed better (and possibly understood better as well), and 2) that social and social-technical tasks simply have more inherent uncertainty associated with them.

⁶ This diagram was drawn by Hank Schactt, former CEO of Lucent, during a class discussion.

There is data from the Silverton experience that strongly indicates that both of these assertions are true. For example, the social-technical task of setting up and running a prototype assembly area, for the combined benefits of learning the build process and improving the work system design, was jeopardized because there was no clear organization to assign that task to. It was not considered Manufacturing Engineering's responsibility because they did not have time budgeted for training. Nor was it Industrial Engineering's responsibility for the same reason. In the end, the integrated launch team took on the task of getting this done, but the very nature of social-technical tasks cutting across traditional organizational boundaries makes them difficult to complete predictably.

As for the notion of their being inherent variability in social tasks, training is a good example. Getting an entire team through training requires scheduling everyone into a few open time slots with the constraint of meeting current production schedules. Add to this the chance of someone being sick or just not showing up, and it becomes apparent that schedule variability is a reality.

The planning process, therefore, needs to recognize and deal with this variability. Large variability in efforts such as lean manufacturing transitions, which contain many interdependencies across functions and through time, needs to be made as small as possible. Otherwise waste and sometimes chaos can overcome the process. Two approaches to dealing with variability must be used: minimizing as much of it as possible, and then recognizing the remaining variability and mitigating its affect.

Planning to Minimize Variability

The first step in reducing variability is the dedication of resources to the transition effort. As mentioned in the previous step, the launch team needs to be chosen to be a representative cross section of the larger organization, and the production team should consist of energetic workers who are willing to take an active role in the change process.

The next, and most critical, step in reducing project variability is the development of a timing plan. An Enhanced Critical Path (ECP) is recommended for its clarity in

recognizing dependencies between social and technical tasks. Some guidelines for the preparation of such a tool are as follows:

1) Establish hard dates

What is the launch date? Are there any other critical dates that need to be met during the design and launch process? These dates will be the foundation of the plan.

2) List all tasks that must be completed before launch

All tasks including technical, social, and those deemed to have both technical and social components must be listed. The level of abstraction should be on the major task level. For example, use a task labeled “Install Drilling Machine” rather than having three tasks called, “Schedule installation”, “Prepare Floor”, and “Install Machine”. This will allow the ECP to be used as intended – as a visual scheduling tool that illustrates technical and social interdependencies.

3) Establish lead times for each task.

Setting realistic stretch goals can be beneficial in driving a project forward, however, over aggressiveness will only lead to frustration as completion dates slip by. On the technical side, lead times for designing and building equipment can usually be established with a high degree of confidence in their accuracy. The only caveat is using the lead time from a vendor who purposefully quotes unrealistically short times to win the contract. Setting social lead times is less exact. Training schedules, willingness of employees to learn, and the time required for everyone to internalize formal lessons are all highly variable, and setting firm lead time on these events is difficult if not impossible. If the planning process is done correctly, however, most of these tasks will be coupled with specific technical tasks which will help add immediacy and relevance to the social schedule.

4) Establish dependencies between tasks

There are three basic types of dependencies between tasks [26]: sequential, parallel, and coupled. Figure 5.5 illustrates these different dependencies. 5.5(a) shows tasks organized sequentially. This format conveys that two of these tasks are dependent on the output of another task, and these tasks must be completed in a strict sequence. 5.5(b) shows four tasks of which the middle two are depended on the first one, but not on each other. The task on the right is dependent on the middle two. The middle tasks are called parallel tasks because they are not dependent on each other, and the most efficient use of resources would be to complete them concurrently. 5.5(c) shows six tasks, four of which are coupled. Coupled tasks are mutually dependent, thus, each requires the output of the other. Coupled tasks can either be completed iteratively, or they can be carried out simultaneously with continual exchanges of information. If they are completed iteratively, then it is assumed that the initial results will be tentative, and that the tasks will most likely have to be repeated a number of times until the desired solution is reached. Also illustrated in the figure are tasks that have a hard coupling and tasks that have a soft coupling. Hard couplings are between two technical or two social tasks. Whereas soft couplings are between a social and a technical task. A soft coupling most often occurs when learning is necessary to accomplish a task. The first iteration might be formal training followed by the first attempt to complete the task. If the results are less than acceptable, then another cycle of learning and doing must be completed. The reason that a soft coupling is distinguished from a hard one is that most often in the planning process they are not explicitly recognized. This is simply a way to bring attention to their importance.

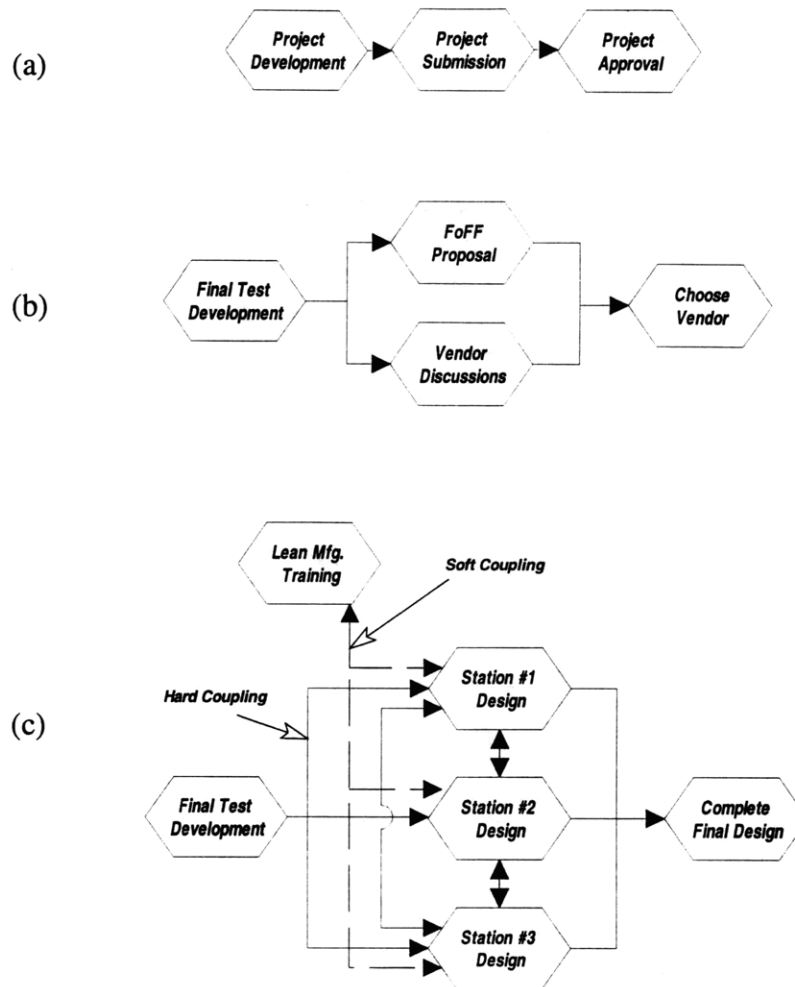


Figure 5.5. Basic task dependency types.

Another technique for reducing variability in the process is to recognize where it shows up, and then circumvent it with creative thinking. An example of doing this is the creation of Single Point Lessons (SPL's). These training tools were developed from the recognition that classroom learning often doesn't fit the scope of what workers need at any given time, and that the attendance and concentration levels in formal class settings is poor. This all leads to high variability on a student-to-student basis of what was actually learned. SPL's circumvent much of that variability by training an employee on the job at the time he or she needs the information most. Appendix II shows an example of a set of SPL's for use in training how to operate and trouble shoot electro-mechanical equipment.

Dealing with Variability

There will always be some variability even with good planning, and dealing with it often separates successful and unsuccessful projects. The simplest way of dealing with it is to leave some slack. The ECP chart in Figure 3.1 purposefully does not have hard deadlines. The completion for each task is shown to occur over the range of about one week so as to convey a successful range of completion times.

If dependencies between tasks change, the team must also be willing to change the schedule. For example, if the launch team realizes that a training exercise should be placed before instead of after a design was scheduled to be completed, then use this new information to re-plan events. If shuffling tasks is impossible, then be as creative as possible to meet the needs of the schedule. For example, in this situation where the coupling between tasks is soft, replacing a training event with a quickly drawn up Single Point Lesson might be a viable alternative.

Designing the Physical Manufacturing System

With a clear vision among management and engineering as to what the lean manufacturing transition should accomplish and a plan in place, it is now time to start designing the system. System design also affects schedule variability from the technical perspective. The completion data shown in Figure 4.6 clearly shows technical tasks being completed with less variability than those that involved social themes, however, that was all *pre-launch* data. Technical variability most often shows up after the entire system is in place. Variability can be reduced up-front by achieving a high quality design, and its effects during the launch can be mitigated by considering the event an ongoing process of data gathering and leaning that evolves over time.

At this point, it is necessary to have enough engineering resources on hand to complete at least the system level design work, and possibly some machine design as well. This is a different approach than many Western manufacturers use. Many businesses rely on suppliers for critical manufacturing system knowledge, however, that is not always

possible with lean systems. As was pointed out in Section 3.6.2, there exist several strategic and practical reasons why it is important to keep a larger percentage of manufacturing engineering in-house. Technical knowledge concerning lean manufacturing is critical at this point for several reasons:

- a) The design should be focused to a specific application. Specific designs are required to “right size” equipment [24] so that unnecessary features that add cost, increase complexity, and reduce reliability are not included. Therefore, system and machine design should be focused only on the needs of the job at hand, and this is not always cost effective for vendors who’s motivation is to gain economies of scale and scope by supplying the same basic system to as many customers as possible.
- b) Important knowledge about the system’s workings is derived from doing the design. This knowledge is critical toward insuring maximum process capability and uptime.
- c) Future improvements are easier to accomplish if the design is done in-house and intimate working knowledge of the system is retained.
- d) Critical process knowledge will not leak to your competition through machine vendors.

This is not to say that machine tool vendors should not be involved in supplying the system, but by doing much of the design in-house, the factors mentioned above will result in a better overall design.

Silverton Sidebar:

Engineers in the Manufacturing Engineering Department designed the new assembly line at Silverton. After the initial design was complete, a bid package was drawn up and several vendors were asked to quote the job. These quotes consisted of technical specifications, time lines, and costs. Analyzing the bids was difficult because there was no one overriding factor that made the choice clear. At this point the team chose to analyze each design using the Analytical Hierarchy Method. Appendix III contains a complete description of the method and the results of the launch team's decision.

Managing the Change

With the plan complete and the design underway, the main focus now resides on managing the change. Here are a few points for doing it.

1) Assign roles within the team

Besides the strictly functional roles within the team (engineering, production, safety/ergonomics etc.), roles should also be assigned for other areas important to team performance. For example, someone should be assigned to each of the following roles: tracking performance to schedule and sending appropriate warnings if necessary, b) performing communications external to the group, c) recording meeting notes, d) creating and driving the agenda. These team roles are each critical to keeping a complex project on target. These roles do not have to be permanent; team members can elect to rotate every few months to prevent stagnation in any one role.

Silverton Sidebar:

The Silverton launch team was pleasantly surprised by the effect that daily communication of meeting notes had on the launch effort. The team's industrial engineer also acted as the meeting note recorder, and she distributed these notes daily to team members and several stakeholders who did not attend the launch meetings. The recipients of these notes included the business unit manager, representatives from the plant safety office, the UAW Employee Resource Coordinator*, and several other stakeholders. These notes conveyed an honest snapshot of how the project was progressing. This use of "boundary communication" [27] had several positive affects including:

- A level of freedom granted by the business unit manager that allowed the team to function with relative autonomy. He was confident that all pertinent issues were being communicated through the published minutes, therefore, he was able to spend the time he normally would have used to follow the project on other pressing matters.
- There existed a level of trust from the Safety and Ergonomics group that traditionally did not exist on new launches. As one safety representative put it, "Normally we are kept in the dark until the last minute on this stuff, and then a lot of rework is required after installation. This time we are being kept informed, and the project will launch sooner because of that."
- The level of communication allowed people to perform their jobs better. As the Employee Resource Coordinator said, "I read every day's note from start to end. Having that information really allows me to understand what the (production) team is up against so I can help them out a lot better."

Thus the process of honest and frequent communication outside the group can have positive effects on how the group is perceived by others. The communication of daily events (even bad news) helped to mold outside perceptions of the team, and it helped with coordination and negotiation with outside groups that the team depended on.

* - The Employee Resource Coordinator (ERC) at the Silverton Plant was a union member who's job was to help ease the transition into workgroups. Details of their job included setting up weekly meeting agendas and being a general resource for the workgroup.

2) Interim Review Process

At least one team review should be scheduled during the design and launch process. This is a chance for the launch team to assemble and reflect on successes and failures. The learning that comes from this should be channeled into corrective action for the remainder of the launch, or if it is too late in the process to make any effective changes, filed for the next launch. Taking the time to reflect, especially during a busy launch, can be difficult, but often the ideas and clarifications that come out of such a meeting are well worth the time [28].

3) Prototype the Design and the Organization

In the case of an assembly operation, prototyping the design of the system can be as simple as gathering around a pile of parts and assembling them by hand to identify any difficulties. This simple experiment can lead to a great deal of learning that can improve the product and process design. A more subtle point is that organizations can be prototyped as well. This opportunity can come in the form of a manufacturing simulation game or even a series of role plays. The advantage of prototyping organizations is that people will have a relatively low risk means of learning how their work life will change. This can lead to personal and organizational improvements that will benefit the actual launch of the manufacturing system.

Silverton Sidebar:

The production team at Silverton got to practice how life would be under the new lean system by running a subset of the job. The welder was brought on-line before the rest of the assembly equipment, and this was used as an opportunity to practice running a job as a workgroup. This included tracking measurables, weekly team meetings, the election of an interim workgroup team leader, problem solving, and simple maintenance and cleaning – none of which were included in any of the production worker's previous jobs. The team had their share of difficulties in getting up and going, however, they did not have to be simultaneously concerned with learning how to work as a team, and with learning the entire welding and assembly process at the same time. While this prototyping experience didn't occur completely off-line, it still offered the team a chance to build skills in the new organization without the complete down-side risks of running the entire job.

Celebration and Continuous Improvement

Don't jump into a continuous improvement mode without first congratulating everyone on a job well done. There is a fine line between developing an immediate improvement mindset and seeming ungrateful to a team that has worked hard. On the other hand resist the urge to collapse over the finish line. There will be a time of struggle as bugs get worked out of mechanical systems, and as the production team learns how to work a lean operation. Use this opportunity for the team to learn how to solve problems, and be sure to document improvement. Improvement rates will be high during a launch period, and visual documentation will serve as proof that the team's efforts are paying off.

5.4 A Systematic View

Another way of looking at the change process described here is through the lens of System Dynamics [29]. The model below illustrates the social and technical structure of a lean change process in terms of a feedback structure. The heart of the model is the reinforcing behavior between the key social and technical components – the Alignment of

Lean Vision and the Quality of Design of the physical system. As each of these elements becomes stronger, it boosts the other as well. Other reinforcing structures in the model include the "knowledge" loop which illustrates that as knowledge of lean manufacturing permeates the business that alignment quality of design will increase. This is affected in several ways beginning with manufacturing engineering designing a better system and moving through to the production team being able to suggest more informed continuous improvements to the system. The final reinforcing loop, "teamwork" is especially strong during the design and launch phase where input from the floor, management, manufacturing engineering, product engineering, etc., can have a strong impact on the design.

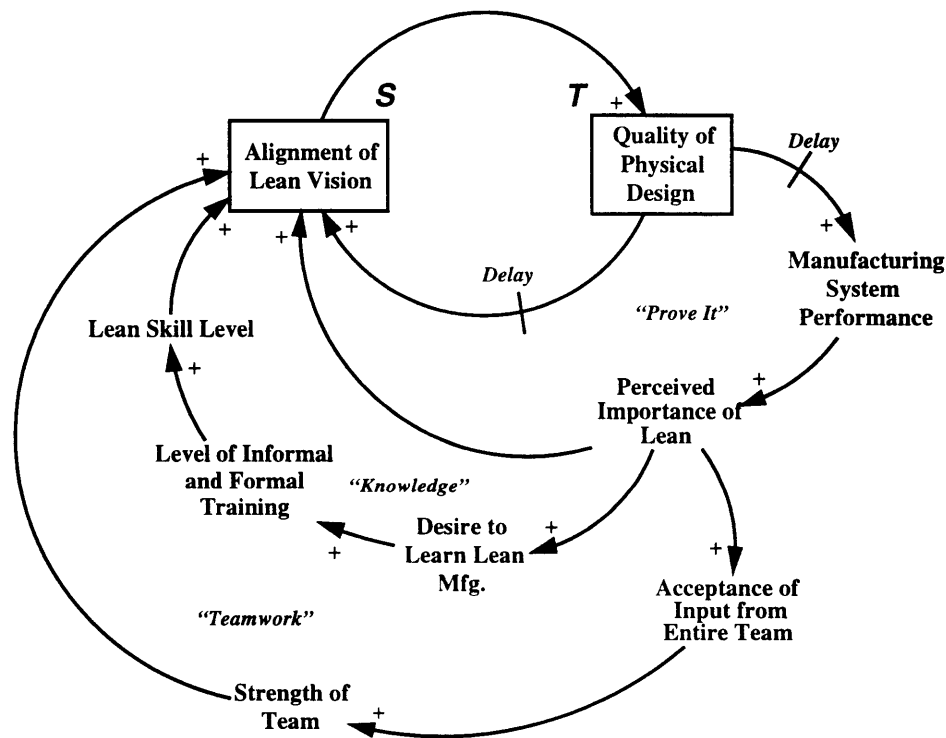


Figure 5.6. Reinforcing behavior in a lean manufacturing system showing the linkage of social [S] and technical [T] components.

The most noteworthy aspect of the model above are the delays that are illustrated after Quality of Design. These are the result of a period of time needing to pass after the

5.5 Conclusions

This section has presented a basic framework for creating successful change when moving from mass production to lean manufacturing. Unlike the literature that focuses on this type of change through only a technical or a social science lens, this process explicitly addresses the interrelationships that exist between the technological and the social components of the change process. These interrelationships are particularly important in lean manufacturing because the process is a delicate optimization of human and physical capital. Machines and humans are each utilized where they each serve the goals of the process best, and furthermore, it is incumbent on the humans in the process to continually re-evaluate their relationship with the machinery. This result can only be achieved if the social and technical initiatives are managed properly.

The social and technical linkage is brought out explicitly in three places in this change model. First of all, it surfaced in the realization that the change process for a lean transition must be based on planning. This planning is part of the process that creates a shared vision among the launch and production teams; an essential component for a decisive and speedy transition. Secondly, the use of the ECP as a planning tool helps the launch team to understand the coupling between many technical and social tasks. The coupling of these tasks may then be leveraged to create better outcomes both on the social and technical sides of the launch. Finally, the quality of the technical design process is highlighted as a key driver of overall success of the system. All the teamwork in the world will not make a technically poor system perform, therefore, technical success is an important factor in the social fabric of the work system.

6. Overall Conclusions and Thoughts

The Silverton experience was a unique learning opportunity because the timing and scope of the project fit in well with the type of work I was hoping to conduct. While I was at the plant helping to implement the new line, and finding time to work off-line on my research, I was able to explore the process with a different lens than my co-workers on the project. They had to worry about many things that I did not, such as running the line after it was launched, and dealing with any political ramifications if it didn't work up to expectations. Meanwhile, even though I was very concerned in making the line work well, I felt separated enough from the outcome to take a critical in-depth look at many aspects of the project. The major observations I had about the overall process fell into two categories: leadership and learning.

It was immediately apparent that strong leadership was required on a project like this because of its scope and importance to the business. I learned that design and implementation of such a system requires a relentless amount of energy in keeping the launch on track because interdependencies between technical and social aspects of manufacturing are intensified in lean operations – especially during the launch process where alignment is critical for keeping to schedule. Silverton's attempt at radical change has taken great dedication from leadership, and it being a union shop, this direction thankfully came from both the management and the union. Without the strong sustaining sponsors that Silverton had, who took a personal stake in the effort's success, credibility for the process would have been lost, and chances of success would have been reduced.

Leadership has also been important at the individual level. While the transition to lean manufacturing involves technology and strong teams of people, it is an inherently individual process. It is not until each and every person throughout the organization's hierarchy has their "aaa-ha" experience that a lean transformation will be complete. Transformation happens when each person learns over time what lean is all about, and this occurs one person at a time.

The long term success of the lean initiative at Ford will also depend greatly on how learnings are captured and disseminated throughout the organization. There currently exists a wide spectrum of how lean is defined. The term “lean”, coined by John Krafcik during his research at the MIT International Motor Vehicle Program, was simply an observation that Toyota seemed to do with less of everything (people and machines) to produce similar output to plants in other parts of the world. What the definition has evolved into means different things to different people. Ford must clarify for itself what lean means, and this cannot only be through the definitions that are passed down from internal and external consultants. By “itself” I mean everyone from plant managers to process engineers and production workers. This definition should be collective or Ford will find itself back in the same place it currently resides – with process, measurement system, and cultures varying widely from one plant to the next. The consultants have done an excellent job of setting the stage, but what they have created should only be considered a kernel of what ultimately will become the Ford Production System. The current initiative was started externally from most plants, but it must continually be refined as learnings from initiatives such as Silverton’s are documented. There are lean launch activities occurring throughout the company that are affected by local constraints. In absence of a mechanism of group learning, there is a real risk of local sub-optimization. Furthermore, there is a similar risk of imposing a single lean model across the company that does not have the benefit of any learning opportunities. If the goal is to catch up to and surpass other companies that are perceived to be more lean than Ford, then this will never happen solely by following others. It will happen through experimentation and subsequent learning by the organization.

Finally, There have been many accounts recently by authors about miraculous and painless transitions to lean. It is my opinion that these musings do little to help the process at sites like the Silverton plant where, with aggressive pursuit, the complete process will take a decade. By their own admission, Toyota has struggled for thirty years with their own lean transition, and upper management at Ford must be very careful not to subvert the process by replacing management that they feel may be acting too slowly. The

role of the sustaining leader, for teaching, support, and vision setting is critical to the process. These men and women must be trusted for their judgment and recognized for their hard work and dedication. Speed is of the essence in a competitive industry, but patience is necessary to conduct a technological and cultural revolution.

A1. Appendix I – Definitions

The intent of this appendix is to provide the reader with clear definitions of the terminology used in this thesis. The general practice of manufacturing is very broad, and thus its language is neither standard nor constant over time.

A1.1 Manufacturing Systems Definitions

Cycle Time - The time that elapses between two sequential parts being operated on by either a single machine or an entire manufacturing system.

Takt Time - The manufacturing system cycle time corresponding to customer demand.

Setup Time - The time required to re-configure tooling to make a different part. The time is measured between the last part that ran before the tool change to the first good part that runs after the tool change. Also referred to as *Changeover Time*.

Lead Time, system throughput time, or Dock-to-Dock Time - The time required to follow one part through the manufacturing system.

Capacity - The highest sustainable production rate that the manufacturing system can achieve. Constraints on this number include product design, product mix, process capability, overtime utilization, up and downstream operations, maintenance strategies etc. Capacity is measured in units produced over a given time interval - e.g. maximum jobs/hour

Production Rate - The rate at which manufactured goods are produced. Production Rate is measured in similar units to capacity (jobs/hour).

Demand Rate - The rate at which the customer requires delivery of a manufactured product.

Volume Flexibility - The ability of a manufacturing system to economically vary the number of units produced over a time scale corresponding to short term demand fluctuations (daily, weekly, monthly).

Mix Flexibility - The ability of a manufacturing system to economically react to changes in the types of products requested by the customer (models, SKU's, etc.)

Work in Process (WIP) - The inventory level within the manufacturing system. Does not take into account raw material or finished goods.

Single Piece Flow - The process by which parts flow through the manufacturing system in a batch size of one.

Batch and Queue - Unlike the concept of Single Piece Flow, Batch and Queue systems operate on many parts at a time. One machine operates on a large *batch* of parts, and then the parts wait in a *queue* to be operated on by the next machine.

Kanban - A simple information system that is used by downstream operations to signal production in upstream operations. Kanban is one method to manage a pull system.

Pull System - The process by which production is scheduled based on demand by downstream operations. This is opposite of a Push System where elaborate planning is used to release raw materials into the production system. Lean manufacturing uses Pull Systems.

Level Production - All operation in the supply chain producing the mix and quantity of parts demanded by the final customer within a given time interval (e.g. daily or weekly).

Balanced Production - All operations in the supply chain producing at the same cycle time. This specific cycle time is termed Takt time.

Synchronous Production - Being able to produce in the sequence that your customer demands. This is often used in situations where assembly plants broadcast production requirements to suppliers, and suppliers are required to deliver parts in the right build order. Autoco's process for synchronized production is In Line Vehicle Sequencing (ILVS).

Error Proofing - A mechanism or process by which manufacturing errors are highlighted and fixed before a part is allowed to proceed to the next operation.

Standardized Work - The process by which the work team decides how the job is to be performed uniformly by everyone. The documented process is used as a basis for continuous improvement and it aids in attaining a predictable output.

Autonomation - The marriage of human and machine to achieve a proper balance between flexibility and speed. The correct level of autonomation will always result in minimum total lifecycle costs for the product.

A1.2 Manufacturing Social System Definitions

Workgroup - a team of production workers responsible for a defined manufacturing task. Also called *production team*.

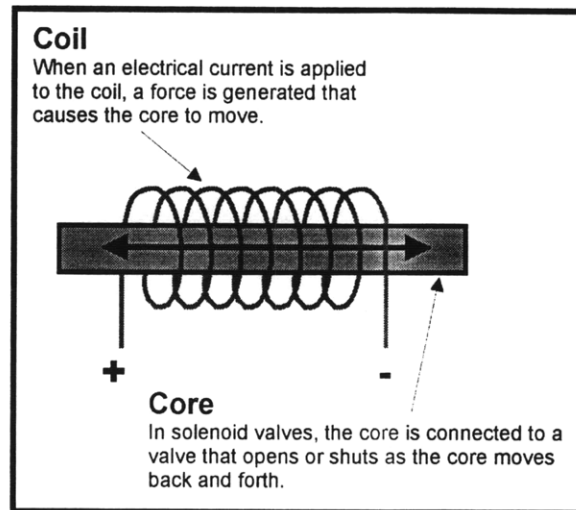
Sociotechnical Systems (STS) - a work system that uses highly autonomous workgroups to carry out work tasks. These systems have proven very popular in continuous processing industries where the team's responsibility for a job can extend from raw material to finished goods. Completely autonomous teams have proven less successful in automotive manufacturing where higher levels of control are necessary to produce predictable output, and where there are many interdependencies with other work teams.

A2. Appendix II - Single Point Lessons

In making the transition from mass production to lean manufacturing, the job responsibilities of direct laborers change dramatically. One of the ways they change is increased responsibility for running day-to-day operations, and included in this are the tasks of minor equipment troubleshooting and predictive maintenance. Furthermore, the job of running complicated equipment is no longer only the responsibility of a few, highly trained personnel. Whereas these tasks were once the responsibility of the “jobsetter”, lean systems rely on the entire workgroup to be able to understand how equipment works and rotate through all operations. Many operators have never had any experience with electrical or mechanical systems, and formal training in these subjects is inappropriate for the circumstances. These Single Point Lessons are meant to be a way of filling the training gap that these employees have in a way that is very complimentary to their situation. For example, when a problem with a piece of production equipment arises that an employee cannot resolve, an advisor would use the SPL to instruct and troubleshoot on the spot. This method of “JIT training” using simple, single themed lessons proved to be effective in their initial use on the welding equipment. In essence, the SPL’s are the creation of a pull system for training.

Single Point Lesson #1

Machine Device: Solenoid Valve



Uses

Solenoids are most often used as on-off or shuttle valves for liquids or gasses.

Operating Principal

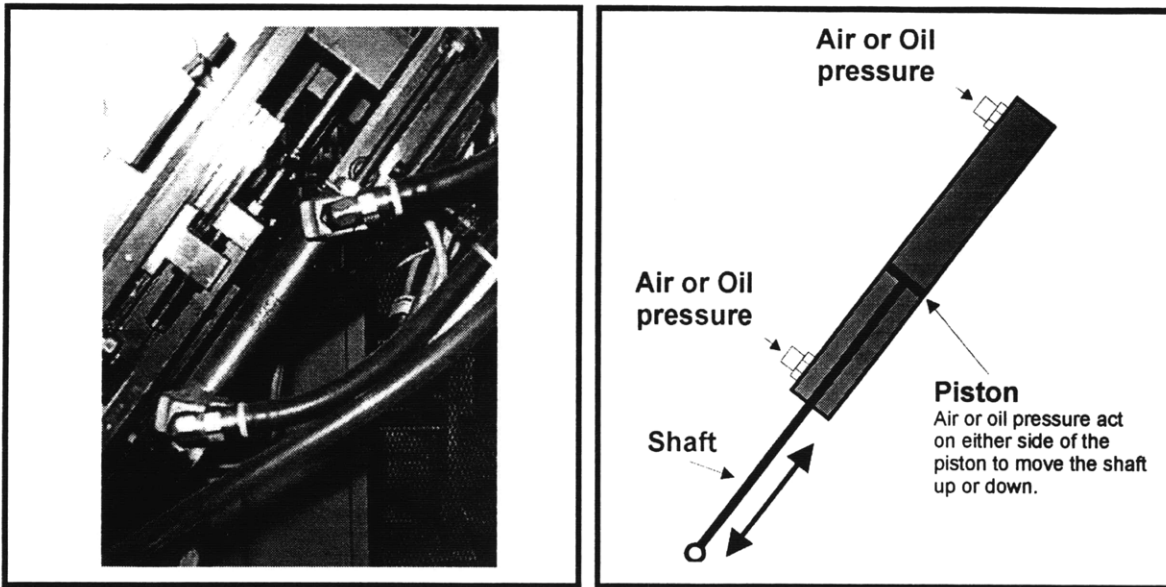
When electrical current is applied to the coil, a force causes the core to move up or down. This movement, in turn, opens or closes a valve.

Trouble Shooting Tips

If the valve is malfunctioning, check it for excessive heat (be careful!). Overheating is a sign that the core is stuck. A gentle tap on the side of the valve will often break the core free from its stuck position. If this does not work, then the quickest and cheapest solution is to have skilled trades change out the valve.

Single Point Lesson #2

Machine Device: Air/Hydraulic Cylinder



Uses

Most actuators for part clamping and part transfer use cylinders. Typically, hydraulic cylinders are used where more force is required. Air cylinders are less costly and less complicated because they use shop air (and don't need a dedicated pump unit).

Operating Principal

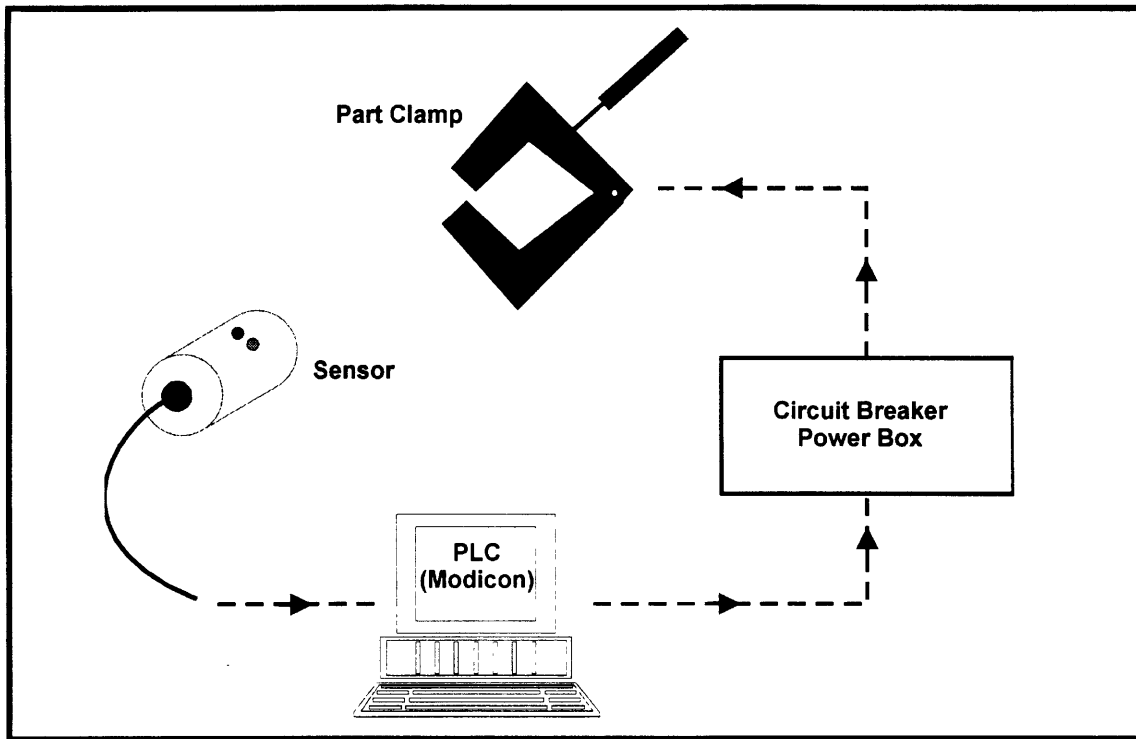
Air or oil pressure is delivered to either the top or the bottom of the piston. This pressure causes the shaft to move in or out.

Trouble Shooting Tips

If a cylinder is not actuating, the first step is to see if air or oil pressure is being delivered properly. Do this by manually activating its shuttle valve with an Allen key. If manual actuation works, then the problem is usually an electronic one. The next places to check should be: 1) the sensor that controls the cylinder's operation – usually a limit switch, or 2) the circuit breaker between the PLC and the actuator.

Single Point Lesson #3

Machine Device: Control Circuit



Uses

Control circuits are used for all automated operations.

Operating Principal

Every actuator (part clamps, transfer stations, weld heads, etc.) uses one or more sensors to control its operation. The PLC "looks" for a signal from the sensor before signaling the actuator to operate.

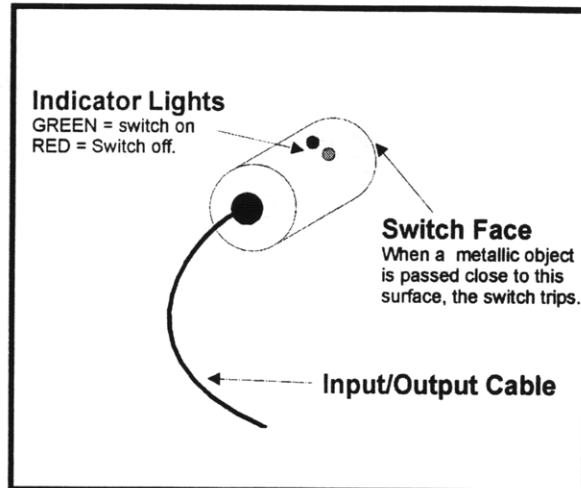
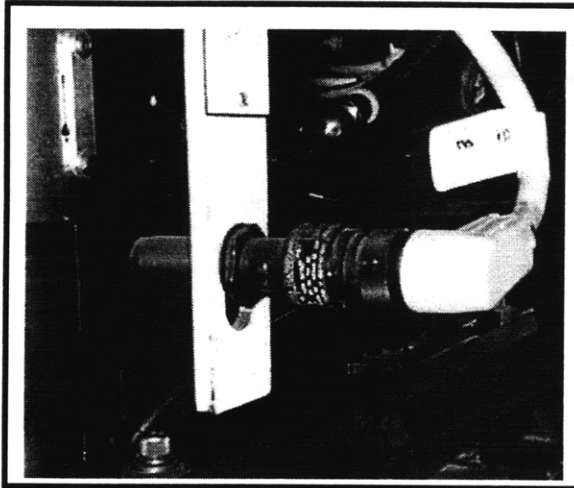
Trouble Shooting Tips

If an actuator does not work:

- 1) Check the sensor to see if it is working (see sensor SPL's).*
- 2) If the sensor works, call skilled trades to check the circuit breaker.*
- 3) If the sensor works and the circuit breaker is on, check the actuation mechanism (air/hydraulic cylinder, motor etc.).*

Single Point Lesson #4

Machine Device: Inductive-Type Limit Switch



Uses

Any time a machine must detect the presence of a part, pallet, or other device a sensor is used.

Operating Principal

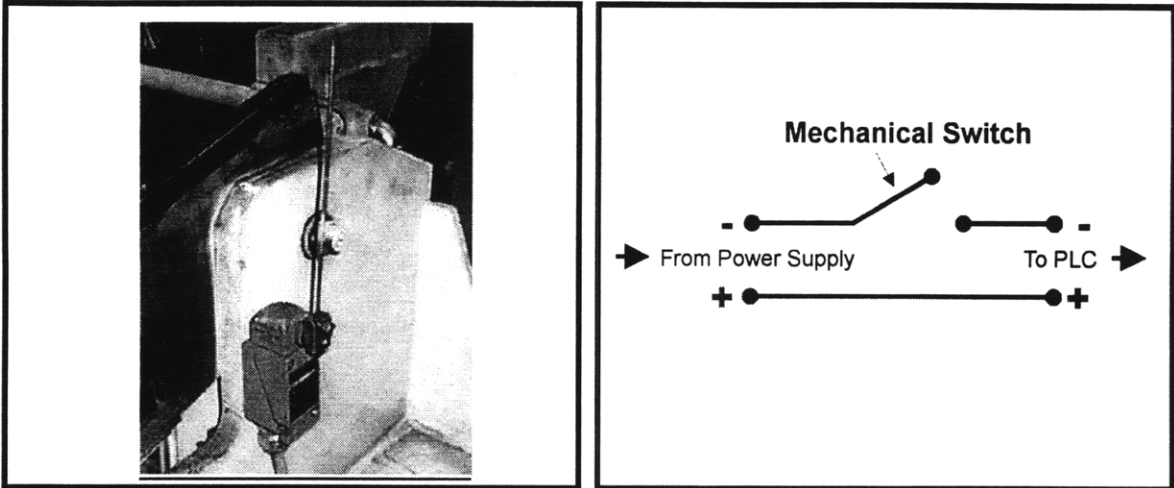
An inductive-type switch requires the presence of a metallic object. When a metallic object passes close to the sensor, the changing magnetic field trips the switch.

Trouble Shooting Tips

Lights on the top of the switch indicate its operating mode. A red light means that the switch is open, and a green light means that the switch is closed. If you think the switch is malfunctioning, swipe a small metallic object (a steel rule or screwdriver works well) in front of the switch. If the light switches from red to green, then the switch is working.

Single Point Lesson #4

Machine Device: Mechanical-Type Limit Switch



Uses

Any time a machine must detect the presence of a part, pallet, or other device a sensor is used.

Operating Principal

A mechanical-type switch uses the movement of a part or machine component to physically move a lever arm. The motion of the lever arm trips the switch.

Trouble Shooting Tips

Lights on the top of the switch indicate its operating mode. A red light means that the switch is open, and a green light means that the switch is closed. If you think the switch is malfunctioning, move the lever remotely with a long stick. If the light switches from red to green, then the switch is working.

A3. Appendix III – Analytical Hierarchy Process

When making the choice between two complex manufacturing system or machine designs, having a systematic way of determining the best decision is helpful. The Analytical Hierarchy Process (AHP) [30] provides such a method by breaking down a decision's complexity into manageable sub-problems. Often, one overriding factor, such as performance of a key component will eliminate choices, but in many instances the choice is not so clear. The AHP process is particularly valuable when dealing with complex problems whose priorities need to be ranked, and where compromises may need to be made to serve the greatest common interest. In complex decisions, wide margins of error are often possible when making tradeoffs, and the AHP builds a framework around the tradeoffs so that they can be more accurately examined.

One of the pre-requisites for applying the AHP is that two or more viable solutions to the problem must be posed. Faced with this set of alternatives where no best answer is clear, the designer, or better yet the design team, can then apply the AHP methodology to come to a decision. The AHP accomplishes this by breaking down the problem into common parts, arranging these parts in a subjectively ranked hierarchical order, and then synthesizing these judgements to determine the overall outcome. The figure below illustrates this process in graphical form.

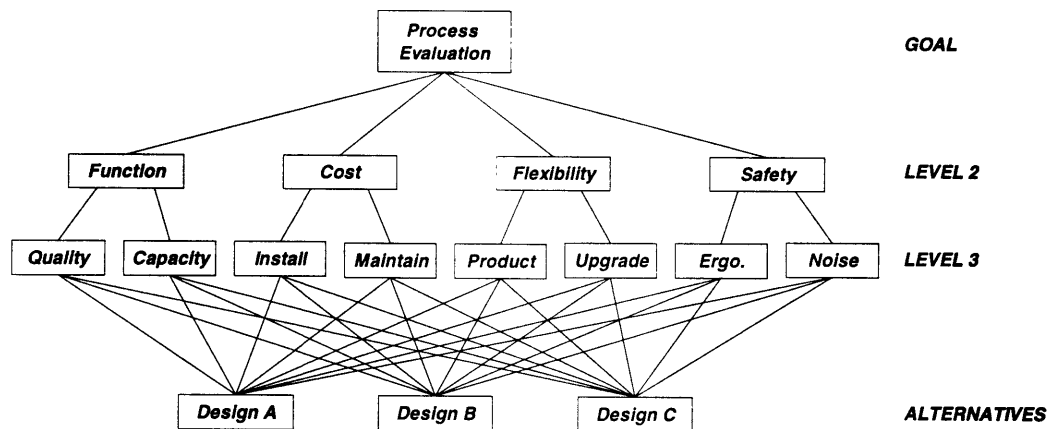


Figure A1. AHP process structure.

The best way to illustrate the use of an AHP is with an example. The output in Figure A2 is the result of an AHP conducted between three possible manufacturing line designs. Box #1 contains the final result. In this case, the C design beat designs A and B by two percentage points. This may seem small, but that is precisely why such an exercise must be done – the choice is a narrow one, and the design team needs to be assured that they have chosen the best option.

The AHP was accomplished in a straight forward step-wise fashion as follows:

1. Level 2 design criteria are chosen and then ranked. In this example, the choices and rankings are illustrated in Box #2. Ranking is done using the scale shown in Table A1. In the example, Function is scaled at 1 and Cost is scaled at 2. This results in 41% of the decision being weighted on Function and 20% being weighted on Cost.
2. Level 3 criteria, shown in Box 3, are then ranked against each other. These are sub-criteria of level 2. For instance Cost can be further sub-divided into Purchase, Installation, and Maintenance costs. In this case, purchase cost far outweighed both installation and maintenance costs.
3. Finally, the design alternatives are ranked against each other (Box 4). Sometimes these rankings are objective, such as in the case of cost, but most of the time they are subjective. For example, safety is difficult to assign a definitive number to, however, it is usually very easy for a design team to come to a consensus on the ranking of different alternatives. In this example, the B design involved more physical strain on the workers, therefore it was ranked worse than the other two alternatives.

Table A1. AHP rating system.

Definition (objective or subjective)	Importance Rating
Equal importance	1
One a little more important than the other	3
One is more important than the other	5
One is much more important than the other	7
Absolute importance	9
Intermediate values to reflect compromise	2,4,6,8
Less important	Reciprocal of Above

1

Final Results:				
A	B	C		
33%	33%	35%		100.0%

2

Function	Cost	Flexib	Mainta.	Safety	Timing		
Function	1.00	2.00	3.00	4.00	5.00	6.00	41%
Cost	0.50	1.00	1.50	2.00	2.50	3.00	20%
Flexibility	0.33	0.67	1.00	1.33	1.67	2.00	14%
Maintainability	0.25	0.50	0.75	1.00	1.25	1.50	10%
Safety	0.20	0.40	0.60	0.80	1.00	1.20	8%
Timing	0.17	0.33	0.50	0.67	0.83	1.00	7%

100%

3

Team Acceptance	Repairs	Test	Tool L.	Material	Product.	
Team Acceptance	1.00	9.00	7.00	7.00	3.00	22%
Repairs	0.11	1.00	1.00	0.78	0.33	2%
Test	0.11	1.00	1.00	0.78	0.33	2%
Tool Locations	0.14	1.29	1.29	1.00	0.43	3%
Material Handling	0.14	1.29	1.29	1.00	0.43	3%
Productivity	0.33	3.00	3.00	2.33	1.00	7%

Purchase	Install	Maintain.		
Purchase	1.00	9.00	5.00	16%
Install	0.11	1.00	0.56	2%
Maintain	0.20	1.80	1.00	3%

Workst.	Other	Reloca.		
Workstation Adjustment	1.00	0.50	3.00	4%
Other Products?	2.00	1.00	6.00	8%
Relocation of Line	0.33	0.17	1.00	1%

Ease o.	Frequ.	PM		
Ease of Maintenance	1.00	0.33	7.00	2%
Frequency	3.00	1.00	21.02	7%
PM	0.14	0.05	1.00	0%

Ergono.	Trip &		
Ergonomics	1.00	7.00	7%
Trip & Fall	0.14	1.00	1%

Timing		
Timing	1.00	7%

4

Team A	Repairs	Test	Tool L.	Material	Product.
Team A	7	5	9		
Repairs	1	1	1		
Test	7	7	9		
Tool L.	1	1	1		
Material	1	1	1		
Product	7	5	7		

Purchase	Install	Maintain.	
Purchase	6	9	4
Install	5	5	9
Maintain.	7	9	5

Workst	Other	Reloca	
Workst	1	1	5
Other	1	1	1
Reloca	3	3	7

Ease o.	Frequ.	PM	
Ease o.	7	9	5
Frequ.	7	9	5
PM	9	7	5

Ergono	Trip &		
Ergono	7	5	7
Trip &	5	5	9

Timing			
Timing	9	9	7

Figure A2. Example of AHP used for line design decision.

The AHP has several advantages when used to aid in complex decisions. First, it removes intuitive thought processes that can be misleading when applied to complicated matters where many opinions and sources of information are present. It also allows the problem to be viewed from both a component perspective and a systems perspective. It forces the problem to be broken down into component parts, but then these components are ranked with respect to their performance in the overall system. Finally, and most important, it promotes communication, and it drives the design team toward consensus on a single alternative.

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